World Academy of Science, Engineering and Technology
International Journal of Nutrition and Food Engineering
Vol:10, No:6, 2016

Natural Radioactivity in Foods Consumed in Turkey

E. Kam, G. Karahan, H. Aslıyuksek, A. Bozkurt

***Abstract*—**This study aims to determine the natural radioactivity levels in some foodstuffs produced in Turkey. For this purpose, 48 different foods samples were collected from different land parcels throughout the country. All samples were analyzed to designate both gross alpha and gross beta radioactivities and the radionuclides' concentrations. The gross alpha radioactivities were measured as below 1 Bq kg^{-1} in most of the samples, some of them being due to the detection limit of the counting system. The gross beta radioactivity levels ranged from 1.8 Bq kg^{-1} to 453 Bq kg^{-1}, larger levels being observed in leguminous seeds while the highest level being in haricot bean. The concentrations of natural radionuclides in the foodstuffs were investigated by the method of gamma spectroscopy. High levels of ^{40}K were measured in all the samples, the highest activities being again in leguminous seeds. Low concentrations of ^{238}U and ^{226}Ra were found in some of the samples, which are comparable to the reported results in the literature. Based on the activity concentrations obtained in this study, average annual effective dose equivalents for the radionuclides ^{226}Ra, ^{238}U, and ^{40}K were calculated as 77.416 μSv y^{-1}, 0.978 μSv y^{-1}, and 140.55 μSv y^{-1}, respectively.

***Keywords*—**Foods, radioactivity, gross alpha, gross beta, annual equivalent dose, Turkey.

I. Introduction

OVER the last century, nuclear materials have found extensive medical, industrial and military applications, which in turn brought about a worldwide concern on radiation exposure of human beings. The nuclear weapon tests and radioactive accidents have also triggered the public fear and as a result a considerable amount of research energy was spent over the last several decades in evaluating the radioactivity content of soil, air, and water [1]. Because the terrestrial or cosmic radioisotopes are always found in the ecosystem and can easily find pathways to enter the metabolisms of plants and animals, such naturally found substances continuously expose people to radiation through the food chain. Therefore, in line with routine measurements of background radiation, a substantial amount of research effort is continually invested in determining how much radioactivity is contained within certain foodstuffs that are also part of the human diet.

A radioactive element in food or water is absorbed in bodies of plants and animals by different mechanisms that are typically dependent on its chemical properties rather than its radioactive characteristics [2]. For example, a plant in need of calcium and potassium will take them through its capillary roots from soil and will not discriminate against the radioactive ^{45}Ca and ^{40}K isotopes. Again the distribution patterns of uranium, thorium and their decay products are affected by certain chemical and biochemical interactions. The amount of these primordial radionuclides in food elements will accordingly depend upon the parent rock and the soil formation along with the transport processes that are involved. Finally, anthropogenic radionuclides such as ^{137}Cs and ^{90}Sr exist in the atmosphere as a result of nuclear weapon tests and radioactive accidents starting from 1950s. These manmade radioactive materials will behave in a similar manner when accumulate on plant leaves and grass in the course of time after fallouts.

Although there are many studies in the literature that present data about the radioactivity in soil, water, and air in some Turkish cities, data on radioactive contents of produces are scarce. This study attempts to determine the level of radioactivity in some foodstuffs that are commonly consumed by people living in Turkey. For this purpose, a radiologic survey that includes gross alpha and gross beta radioactivity measurements along with concentrations of naturally occurring radionuclides in 48 food samples was carried out. The results were compared with those from other countries.

Erol Kam is with the Science Faculty, Yıldız Technical University, Esenler, Istanbul, Turkey (e-mail: erolkam@hotmail.com).

II. Materials and Methods

A. Sample Collection and Preparation

The samples of fruits and vegetables which were raised in different land parcels throughout the country were purchased from different sellers and were taken as individual food items rather than mixed diet samples. The measurement samples were first washed with tap water and then with distilled water, and peeled when necessary. The wet and dried masses were recorded by subtracting the edible portion from the total to account for the loss of moisture from the edible part during the time of preparation.

Almost all foods samples were prepared in two different methods: Home use form and ash form. In home use preparation, solid and liquid samples were first air-dried at room temperature after breaking into small sizes. The samples were then put into 1000 mL Marinelli beakers which were previously treated with dilute HCL to prevent any possible contamination. Finally, each tightly sealed container was stored for a period of 1 month to attain a radioactive equilibrium between ^{226}Ra and its daughters [3]. The second method involved reducing the samples to ash form where one of two different techniques could be used. In wet ashing, the sample is treated using oxidant nitric acid (HNO_3) whereas dry ashing method is much simpler, takes less time, and is more suitable for radionuclides that do not vaporize at ashing temperature (since some radionuclides in the sample may be lost at high temperatures). In this study, dry ashing method was adopted for all foodstuffs except liquid samples such as water and olive oil that were evaporated at 55 °C. For each dried food crop, a mass of 100 g was taken to ash in high temperature resistant porcelain plates using an electric furnace. The temperature for dry ashing varied where an upper limit was generally around 450 °C [4]. The ashing time, on the other hand, depended on the type and quantity of the material where it was more than a day for some of the samples. Measurements of the ashed weight were necessary for calculations of radioactivity and radionuclide concentrations and yield. At the end of this process, the samples in ash form were homogenized, weighed and tied up in 100 mL polyethylene beakers, and finally stored for a period of 1 month to achieve an approximate secular equilibrium between ^{226}Ra and its daughters before performing the radioisotope analyses.

B. Radioactivity Measurements

Gross alpha and gross beta radioactivity measurements were performed by Krieger method [5] using a proportional gas flow counter (Ortec Telenet Systems). All food samples were counted in counter systems after incineration. The beta counting system had a low background detector with gas-flow window type approximately 5 cm in diameter. The gas for each detector was a mixture of 90% argon and 10% methane. All samples were placed in a 5 cm diameter stainless steel planchette for counting. The alpha counting system was calibrated using a ^{238}U standard source while the beta system was calibrated with a ^{40}K standard source. The counting time was 1000 minutes for gross alpha measurements and 100 minutes for gross beta measurements.

Gamma spectrometric measurements were made with a coaxial high purity germanium detector (Canberra GC 1520 model) having 16 % relative efficiency and 1.9 keV energy resolution (FWHM) at 1332 keV gamma transition of ^{60}Co. To ensure accurate quantitative measurements, the detector was calibrated by two different certified gamma ray standard sources in 1000 mL Marinelli beaker for home use form and mixed radionuclides in 100 mL beaker for ashed form, the same size and type used to count the samples. The counting time for each sample was 50,000 s which produced sufficiently strong peaks and small counting errors. The uncertainties in all measurements were about 2σ. The background spectra were also measured under the same conditions used for the reference materials and the samples.

Spectrometric analyses were carried out for the natural radionuclides ^{226}Ra, ^{238}U and ^{40}K. The activity of each sample was determined using the total net counts under the selected photo-peaks (186 keV for ^{226}Ra, 1461 keV for ^{40}K), the measured photo-peak efficiency, the gamma intensity and the sample weight. The activity concentrations of these radionuclides were obtained for each sample (in units of Bq kg^{-1}) after correcting for background and Compton contributions.

TABLE I A
GROSS ALPHA AND GROSS BETA RADIOACTIVITIES (BQ KG^{-1}) IN REFINED PRODUCTS

Food	Gross α	Gross β
Flour	0.352 ± 0.080	92.22 ± 3.42
Olive oil (Bq l^{-1})	ND	1.80 ± 0.02
Sugar	ND*	10.31 ± 0.24

*not determined

TABLE I B
GROSS ALPHA AND GROSS BETA RADIOACTIVITIES (BQ KG^{-1}) IN ANIMAL PRODUCTS

Food	Gross α	Gross β
Beef	0.130 ± 0.033	58.11 ± 1.74
Chicken	0.035 ± 0.001	84.30 ± 3.08
Egg	0.008 ± 0.002	48.12 ± 2.56
Fish	ND	69.50 ± 1.08
Milk (Bq l^{-1})	ND	43.67 ± 1.82

TABLE I C
GROSS ALPHA AND GROSS BETA RADIOACTIVITIES (BQ KG^{-1}) IN FRUITS

Food	Gross α	Gross β
Apple	0.590 ± 0.113	25.41 ± 1.36
Apricot	0.091 ± 0.002	80.29 ± 2.56
Cherry	0.074 ± 0.004	36.91 ± 3.12
Grapes	ND	61.79 ± 1.45
Olive	0.400 ± 0.082	49.23 ± 2.87
Orange	ND	38.69 ± 1.72
Peach	0.172 ± 0.060	53.76 ± 2.77
Pear	0.082 ± 0.016	29.91 ± 1.34
Plum	0.363 ± 0.043	32.44 ± 1.29
Strawberry	0.353 ± 0.090	32.41 ± 2.19
Tangerine	ND	32.02 ± 1.38
Watermelon	ND	39.12 ± 2.23

TABLE I D
GROSS ALPHA AND GROSS BETA RADIOACTIVITIES (BQ KG^{-1}) IN VEGETABLES

Food	Gross α	Gross β
Aubergine	0.202 ± 0.035	36.40 ± 1.89
Cabbage (dark)	0.401 ± 0.120	75.80 ± 3.00
Cabbage (red)	0.130 ± 0.042	68.10 ± 2.37
Cabbage (white)	0.262 ± 0.067	48.33 ± 1.92
Carrot	0.442 ± 0.103	56.29 ± 2.16
Cauliflower	0.242 ± 0.074	59.23 ± 2.28
Celery	0.520 ± 0.140	70.61 ± 2.39
Chard	ND	49.43 ± 2.82
Cucumber	0.120 ± 0.041	39.24 ± 1.67
Curly	ND	34.70 ± 3.59
Green beans	0.112 ± 0.033	61.52 ± 2.25
Green pepper	0.091 ± 0.020	43.10 ± 1.76
Leek	0.150 ± 0.041	58.33 ± 2.16
Marrow	0.213 ± 0.022	50.89 ± 1.92
Onion	0.262 ± 0.071	57.02 ± 2.06
Pea	0.093 ± 0.002	35.36 ± 2.51
Potato	0.162 ± 0.048	74.41 ± 3.36
Purslane	0.530 ± 0.122	101.25 ± 2.82
Red radish	0.123 ± 0.045	47.65 ± 1.77
Romaine lettuce	0.133 ± 0.041	79.63 ± 2.60
Spinach	0.062 ± 0.011	100.53 ±3.08
Tomato	0.173 ± 0.053	37.39 ± 1.60

TABLE I E
GROSS ALPHA AND GROSS BETA RADIOACTIVITIES (BQ KG^{-1}) IN LEGUMINOUS PLANTS

Food	Gross α	Gross β
Chickpea	0.470 ± 0.009	197.02 ± 5.72
Haricot beans	0.471 ± 0.102	453.02 ± 15.64
Lentil (green)	0.562 ± 0.013	200.12 ± 9.12
Lentil (red)	0.744 ± 0.190	176.03 ± 3.36
Rice	ND	167.30 ± 3.31
Wheat	0.772 ± 0.142	77.14 ± 4.63

III. RESULTS

A. Gross Alpha and Gross Beta Radioactivity Measurements

Food samples (48 in total) were first analyzed by gathering into five groups: refined products, animal products, fruits, vegetables and leguminous plants. The gross alpha and gross beta radioactivity results in the studied foodstuffs are given in Tables I A-E. The gross alpha radioactivity varies between 0.008 Bq kg^{-1} (egg) and 0.772 Bq kg^{-1} (wheat). This quantity was the highest in leguminous plants and could not be determined in some foods such as fish, milk, rice, some fruits and some vegetables. In all the samples investigated, gross beta concentrations were found at higher levels than those of alpha and varied between 1.8 Bq kg^{-1} (olive oil) and 453 Bq kg^{-1} (haricot beans). Particularly, leguminous plants had very high gross beta radioactivities.

B. Radionuclide Activity Concentrations

TABLE II A
RADIONUCLIDE CONCENTRATIONS (BQ KG^{-1}) IN REFINED PRODUCTS

Food	^{226}Ra	^{238}U	^{40}K
Flour	1.15 ± 0.11	0.21 ± 0.02	51.2 ± 20
Olive oil (Bq l^{-1})	ND	ND	1.66 ± 0.36
Sugar	ND	ND	7.80 ± 1.24

TABLE II B
RADIONUCLIDE CONCENTRATIONS (BQ KG^{-1}) IN ANIMAL PRODUCTS

Food	^{226}Ra	^{238}U	^{40}K
Beef	ND	0.32 ± 0.16	52.17 ± 5.70
Chicken	ND	ND	74.23 ± 12.61
Egg	ND	ND	46.73 ± 5.21
Fish	ND	ND	67.56 ± 6.98
Milk (Bq l^{-1})	ND	ND	42.04 ± 5.00

TABLE II C
RADIONUCLIDE CONCENTRATIONS (BQ KG^{-1}) IN FRUITS

Food	^{226}Ra	^{238}U	^{40}K
Apple	ND	ND	19.23 ± 3.60
Apricot	ND	ND	59.25 ± 8.56
Chery	ND	ND	28.30 ± 5.90
Grape	ND	ND	58.50 ± 3.33
Olive	1.29 ± 0.40	ND	43.25 ± 2.81
Orange	ND	ND	23.70 ± 2.20
Peach	ND	ND	51.18 ± 2.96
Pear	ND	ND	21.86 ± 1.85
Plum	ND	ND	25.70 ± 5.10
Strawberry	ND	ND	27.87 ± 2.58
Tangerina	ND	ND	25.60 ± 7.32
Watermelon	ND	ND	36.28 ± 2.90

TABLE II D
RADIONUCLIDE CONCENTRATIONS (BQ KG^{-1}) IN VEGETABLES

Food	^{226}Ra	^{238}U	^{40}K
Aubergine	ND	ND	32.90 ± 4.27
Cabbage (dark)	ND	ND	70.76 ± 4.82
Cabbage (red)	0.21 ± 0.11	ND	59.70 ± 8.03
Cabbage (white)	2.3 ± 0.97	ND	42.00 ± 3.24
Carrot	ND	ND	43.30 ± 6.00
Cauliflower	2.18 ± 0.88	ND	55.60 ± 5.02
Celery	ND	ND	63.02 ± 7.80
Chard	ND	ND	36.70 ± 11.4
Cucumber	1.05 ± 0.24	0.14 ± 0.05	34.54 ± 6.90
Curly	1.35 ± 0.61	ND	28.09 ± 6.26
Green beans	1.17 ± 0.86	ND	36.61 ± 6.22
Green pepper	3.95 ± 1.42	ND	39.87 ± 6.20
Leek	0.26 ± 0.12	0.06 ± 0.02	54.82 ± 980
Marrow	ND	ND	37.70 ± 13.20
Onion	0.48 ± 0.25	ND	53.90 ± 5.31
Pea	ND	ND	31.80 ± 3.40
Potato	0.94 ± 0.45	ND	61.30 ± 12.42
Purslane	ND	ND	99.65 ± 11.56
Red radish	1.63 ± 0.62	ND	42.70 ± 11.00
Romaine lettuce	1.44 ± 0.37	0.21 ± 0.04	75.30 ± 7.20
Spinach	0.41 ± 0.20	ND	78.29 ± 6.42
Tomato	0.84 ± 0.46	ND	32.40 ± 4.90

TABLE II E
RADIONUCLIDE CONCENTRATIONS (BQ KG^{-1}) IN LEGUMINOUS PLANTS

Food	^{226}Ra	^{238}U	^{40}K
Chickpea	ND	0.58 ± 0.12	177.80 ± 17.70
Haricot beans	ND	ND	374.33 ± 12.56
Lentil (green)	ND	0.36 ± 0.03	183.92± 19.20
Lentil (red)	ND	ND	165.21 ± 10.61
Rice	ND	ND	129.50 ± 12.33
Wheat	1.02 ± 0.52	0.68 ± 0.11	67.03 ± 8.90

The amount of ^{226}Ra, ^{238}U, and ^{40}K isotopes were determined in the foodstuffs collected. The activity concentrations of these radionuclides are given in Tables II A-E. As mentioned earlier, the samples prepared in both home use and ashed forms were counted by gamma spectroscopy. Since the measurements from each method were found to be very close, the results were reported in Tables II A-E as the average of both methods.

Because naturally found ^{40}K emits both gamma and beta rays, the gamma activity concentration of ^{40}K were found very close to the gross beta activity in all samples. The highest ^{40}K radioactivity concentrations were measured in leguminous plants as is the case in gross beta measurements. The maximum gamma radioactivity was determined as 374.32 Bq kg^{-1} in haricot beans. The smallest ^{40}K concentration was found as 1.66 Bq kg^{-1} in olive oil.

^{226}Ra were found only in some of the foodstuffs included in the study, most of them being vegetables. 32 of the 48 samples did not reveal any ^{226}Ra activity. The maximum activity concentration for the radionuclide was found as 3.95 Bq kg^{-1} in green pepper. Only a limited number of samples showed ^{238}U activities, most of them being leguminous plants or vegetables. The highest activity concentration for this radioisotope was measured as 0.68 Bq kg^{-1} in wheat.

IV. Discussion

The radioactivity contents of various foodstuff have been extensively studied in different parts of the world. Table III provides the specific activities of the foods measured in some of these studies along with findings of this work [6-13]. As seen, our results agree pretty well with the literature data.

For all foodstuffs, a close relationship exists between gamma activity concentration of ^{40}K and gross beta radioactivity. Table IV provides $^{40}K/T_\beta$ ratios for the samples investigated. The average activity of ^{40}K and T_β in foods are 72.36 Bq kg^{-1} and 61.99 Bq kg^{-1}, respectively. The average $^{40}K/T_\beta$ ratio is about 0.857 from which one can conclude that a substantial portion of gross beta radioactivity in foods emanate from the natural ^{40}K isotope. The average concentration of ^{40}K in adults is 60 Bq kg^{-1} [14].

Potassium is a significant element for human health. Like other minerals, amount of potassium in body varies depending on the age of person where 0.012% of natural potassium is ^{40}K. Any radionuclide that enters the body by means of foods or beverages continuously exposes it in proportion with the element's biological half-life. Therefore, it is important to calculate the annual effective dose equivalent resulting from exposure to natural radionuclides such as ^{40}K, ^{226}Ra and ^{238}U in the foodstuffs that are part of a person's diet.

The annual effective dose equivalent from the radioactive contents in a daily consumption of a mixture of foods can be easily calculated despite the habits of consumption by people may differ in real life. A typical amount of average daily consumption for every foodstuff included in this study is also given in Table IV. These figures were estimated from annual consumption of an ordinary family because there are no such statistical data for Turkish people. The intake amounts for fish, chicken and flour were taken from the corresponding WHO reports [15]. In total, a person was assumed to consume a daily mix of 1274 g of all these foods and as a result takes 276.5 Bq, 21.7 Bq, and 22668.7 Bq of annual total activity from ^{226}Ra, ^{238}U, and ^{40}K, respectively. Using the corresponding dose conversion factors for these radionuclides (^{226}Ra: $2.8*10^{-7}$ Sv Bq^{-1}; ^{238}U: $4.5*10^{-8}$ Sv Bq^{-1}; ^{40}K: $6.2*10^{-9}$ Sv Bq^{-1} [16], the annual effective dose equivalents (AEDE) for ^{226}Ra, ^{238}U, and ^{40}K as 77.416 μSv y^{-1}, 0.978 μSv y^{-1}, and 140.55 μSv y^{-1}, respectively from the data obtained in this study.

TABLE III
Radionuclide Concentrations Measured in Different Countries' Foodstuffs

Food	Country	^{226}Ra (Bq kg^{-1})	^{238}U (Bq kg^{-1})	^{40}K (Bq kg^{-1})
Beef	Brasil [6]		0.5	
	Germany [7]	0.11		
	Turkey	ND	0.32	52.17
Chicken	Brasil [6]	0.04-0.16		
	Turkey	ND	ND	74.23
Cucumber	Egypt [8]			43-68
	India [12]	0.097		29.67
	Turkey	1.05	0.14	34.54
Milk (Bq l^{-1})	Brasil [6]	0.029-0.21		
	Egypt [8]			79
	India [12]	2.5		34.35
	Jordan [13]			40.8
	Turkey	ND	ND	42.04
Onion	Egypt [8]			44-68
	Turkey	0.48	ND	53.90
Potato	Germany [7]			130-180
	Egypt [8]			76-124
	Turkey	0.94	ND	61.3
Rice	China [9]	0.07-0.23		
	Germany [7]			90-110
	India [12]	3.07		120.2
	Turkey	ND	ND	129.54
Tomato	Egypt [8]			39-84
	India [12]	0.06		71.92
	Turkey	0.84	ND	32.4
Wheat	Germany [7]			97-130
	India [10]	>0.5		
	Pakistan [11]	0.98		109.27
	Turkey	1.02	0.68	67

TABLE IV
$^{40}K/T_\beta$ Ratios and Yearly Consumption Amounts in Foods and Annual Effective Dose Equivalent (AEDE)

Food	T_β (Bq kg^{-1})	^{40}K (Bq kg^{-1})	$^{40}K/T_\beta$ (Bq kg^{-1})	Consumption (kg y^{-1})	AEDE (μSv y^{-1})		
					^{226}Ra	^{238}U	^{40}K
Flour	92.22	51.20	0.56	73.2	23.57	0.692	23.24
Olive oil (Bq l^{-1})	1.80	1.66	0.92	4.7			0.05
Sugar	10.31	7.80	0.76	14.6			0.71
Beef	58.11	52.17	0.90	5.1		0.07	1.65
Chicken	84.30	74.23	0.88	5.1			2.35
Egg	48.12	46.73	0.97	9.8			2.84
Fish	69.50	67.56	0.97	5.1			2.14
Milk (Bq l^{-1})	43.67	42.04	0.96	50			13.03
Apple	25.41	19.23	0.76	28.8			3.43
Apricot	80.29	59.25	0.74	2.9			1.07
Cherry	36.91	28.30	0.77	2.9			0.51
Grape	61.79	58.50	0.95	8.1			2.94
Olive	49.23	43.25	0.88	8.9	3.21		2.39

Food	T_β (Bq kg^{-1})	^{40}K (Bq kg^{-1})	^{40}K/T_β (Bq kg^{-1})	Consumption (kg y^{-1})	AEDE (μSv y^{-1})		
					^{226}Ra	^{238}U	^{40}K
Orange	38.69	23.70	0.61	5.8			0.85
Peach	53.76	51.18	0.95	5.1			1.62
Pear	29.91	21.86	0.73	5.1			0.69
Plum	32.44	25.70	0.79	2.9			0.46
Strawberry	32.41	27.87	0.86	1.8			0.31
Tangerine	32.02	25.60	0.80	5.8			0.92
Watermelon	39.12	36.28	0.93	9.8			2.20
Aubergine	36.40	32.90	0.90	6.9			1.41
Cabbage (dark)	75.80	70.76	0.93	2.9			1.27
Cabbage (red)	68.10	59.70	0.88	2.9	0.17		1.07
Cabbage (white)	48.33	42.00	0.87	5.1	3.28		1.33
Carrot	56.29	43.30	0.77	8.1			2.17
Cauliflower	59.23	55.60	0.94	3.7	2.26		1.28
Celery	70.61	63.02	0.89	1.5			0.59
Chard	49.43	36.70	0.74	1.5			0.34
Cucumber	39.24	34.54	0.88	8.1	2.38	0.05	1.73
Curly	34.70	28.09	0.81	3.7	1.40		0.64
Green beans	61.52	36.61	0.60	8.1	2.65		1.84
Green pepper	43.10	39.87	0.93	8.1	8.96		2.00
Leek	58.33	54.82	0.94	5.1	0.37	0.01	1.73
Marrow	50.89	37.70	0.74	2.9			0.68
Onion	57.02	53.90	0.95	6.9	0.93		2.31
Pea	35.36	31.80	0.90	2.9			0.57
Potato	74.41	61.30	0.82	50.6	13.32		19.23
Purslane	101.25	99.65	0.98	1.8			1.11
Red radish	47.65	42.70	0.90	2.9	1.32		0.77
Romaine lettuce	79.63	75.30	0.95	1.8	0.73	0.02	0.84
Spinach	100.53	78.29	0.78	5.1	0.59		2.48
Tomato	37.39	32.40	0.87	50	11.76		10.04
Chickpea	197.02	177.80	0.90	1.8		0.05	1.98
Haricot beans	453.02	374.33	0.83	3.7			8.59
Lentil (green)	200.12	183.92	0.92	1.8		0.03	2.05
Lentil (red)	176.03	165.21	0.94	1.8			1.84
Rice	167.30	129.50	0.77	8.1			6.51
Wheat	77.14	67.03	0.87	1.8	0.51	0.06	0.75
Average	72.414	61.934	0.851				
Total				1.274	1.489	0.019	2.703

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