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Original Article

Determination of some useful radiation interaction parameters for waste foods

F. Akman [a, *], I.H. Geçibesler [b], M.I. Sayyed [c], S.A. Tijani [d, e], A.R. Tufekci [f], I. Demirtas [f]

[a] *Bingöl University, Vocational School of Technical Sciences, Department of Electronic Communication Technology, 12000 Bingöl, Turkey*
[b] *Bingöl University, Health Faculty, Laboratory of Natural Product Research, 12000 Bingöl, Turkey*
[c] *Department of Physics, Faculty of Science, University of Tabuk, Tabuk, Saudi Arabia*
[d] *Department of Physics, Faculty of Science, King Abdulaziz University, Jeddah 21589, Saudi Arabia*
[e] *National Institute of Radiation Protection and Research, Ibadan, Nigeria*
[f] *Cankiri Karatekin University, Faculty of Science, Department of Chemistry, 18000 Cankiri, Turkey*

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ABSTRACT

The mass attenuation coefficients (μ/ρ) of food waste samples (pomegranate peel, acorn cap, lemon peel, mandarin peel, pumpkin peel, grape peel, orange peel, pineapple peel, acorn peel and grape stalk) have been measured employing a Si(Li) detector at 13.92, 17.75, 20.78, 26.34 and 59.54 keV. Also, the theoretical values of the mass attenuation coefficients have been evaluated utilizing mixture rule from WinXCOM program. The results showed that the lemon peel has the highest values of μ/ρ among the selected samples. From the obtained mass attenuation coefficients, we determined some absorption parameters such as effective atomic number (Z_{eff}), electron density (N_E) and molar extinction coefficient (ε). It was found that the Z_{eff} values of all food wastes lie within the range of 4.034–7.595, whereas the N_E of the studied food wastes was found to be in the range of $0.301-1.720 \times 10^{25}$ (electrons/g) for present energy region.

1. Introduction

Food waste consists of the food system from the farm, post-harvest, cultivating, retailing and the consumers. Food wastes are the single largest type of waste entering the landfills. Each wasted food means wasted money for businesses and housing. These waste foods are part of the hazards such as methane and greenhouse gases. One of the studies to provide for the recycling of these wastes may be a radiation shielding work area. In addition, food is exposed to radiation for preservation, control of insects, prevention of food-borne illness, extend the shelf life, delay of sprouting and ripening, and sterilization. It is very important to know the radiation attenuation characteristics of food at the applied radiation.

Food waste has been identified as one of the factors that has overburdened the global environment in recent years. A lot of wastes are being discarded in large amounts [1,2] considering the location and method of harvest. In recent times, compositional studies of food wastes suggest the presence of bioactive compounds, which are generally primary and secondary plants' metabolites. Some of the metabolites include phenolics, alkaloids, glycosides, volatile oils, mucilage, gums [3]. In addition, fruit peels' bioactive compounds contain a higher percentage of antioxidant activities [4] and can be used in the production of nutraceuticals and other products with a good fraction of fibers [5]. Because of the potential importance of the chemical composition of medicinal plants, many studies have been conducted [6–10].

Mass attenuation coefficient of different materials is very important for x-ray fluorescent (XRF) analysis because it helps in selecting the optimum reference sample during elemental analysis [11]. Different researchers have carried out works on determination of the mass attenuation coefficients of medicinal plants. Morabad and Kerur [12] experimentally determined the mass attenuation coefficients of some fruits, leaves, stem and seeds, which are known to be medicinal using a NaI(Tl) detector at 8.136, 13.596, 17.781, 22.581 and 32.891 keV. Their result showed a linear correlation in relation to the energies. Teerthe and Kerur [13] also worked on the x-ray mass attenuation coefficient of medicinal plants at low energies, their result is useful for XRF analysis and their experimental result compared well with the theoretical. Trunova et al. [11] worked on the measurement of the mass attenuation coefficient

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* Corresponding author.
E-mail address: fakman@bingol.edu.tr (F. Akman).

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of some biological samples from 7 to 12 keV. Their result showed a significant variation among the biological samples. Variation between plant and animal tissue reached 47% and about 22% with different animal tissues. Tousi et al. [14] measured the mass attenuation coefficients of Eremunus – Rhizophora spp. particle boards using x-rays in the energy range 16.63–25.3 keV. The result from this work showed that Eremunus – Rhizophora spp. particle boards could be used as phantoms in diagnostic radiology.

Mass attenuation coefficients of food wastes like pomegranate peel, lemon peel, mandarin peel, pumpkin peel, grape peel, orange peel, pineapple peel, acorn peel, grape stalk and acorn cap are not available in the literature. So, this work has produced the mass attenuation coefficients, molar extinction coefficients, effective atomic numbers and electron densities of these wastes to help in the XRF analysis of any other similar wastes because of the potential usage of these wastes in medicine.

In the present work, mass attenuation coefficients (μ/ρ) of ten food waste samples were measured by using gamma-ray transmission method at 13.92, 17.75, 20.78, 26.34 and 59.54 keV photon energies. The gamma-ray attenuation measurements were measured using ^{241}Am point sources. The molar extinction coefficients (ε), effective atomic numbers (Z_{eff}) and electron densities (N_E) for the present food wastes samples were derived from the measured μ/ρ values. The experimental values of μ/ρ, ε, Z_{eff} and N_E were compared with those obtained theoretically using WinXCOM program. To best of our knowledge none of the studies have evaluated the photon attenuation characterizations of food waste samples and this encourages us to investigate the radiation attenuation parameters for the present samples. Therefore, understanding the physical interaction properties of food wastes with X- or gamma-rays has become essential for many industrial applications. Besides, the results obtained from this work can be useful in the design of new industrial radiation shielding products using waste foods and in the development of non-toxic shielding materials.

2. Materials and method

2.1. Sample preparation

The food wastes used in the study were obtained from local markets in Bingöl city in Turkey. After the food wastes were separated from their edible parts, the wastes were placed on unprinted papers and allowed to dry in airless, sunless laboratory conditions at 25 °C. After the drying process, the wastes were pulverized by grinding the laboratory type mill. Powdered food wastes were pelleted to 13 mm in diameter with the aid of a laboratory-type hydraulic pellet press. Perkin-Elmer brand elemental analysis instrument 2400 CHNS/O series II system was used to determine the chemical composition of food wastes. Total carbon, hydrogen and nitrogen in food wastes were determined by minor revisions according to European standard EN15104: 2011. The oxygen content in the samples was calculated by the following formula.

$$\text{Oxygen}\ (\%) = 100\text{-[carbon\%+hydrogen\%+nitrogen\%]}_{(\text{Lighest moist basis})}.$$

The chemical compositions and physical densities of the food wastes are shown Table 1.

2.2. Experimental details

The mass attenuation coefficients (μ/ρ) of the food wastes were determined at 13.92, 17.75, 20.78, 26.34 and 59.54 keV using the transmission geometry as shown in Fig. 1. The measurements were conducted using the Si(Li) semiconductor detector system combined with multichannel analyzer (MCA), a radioactive point source, food waste (as the absorber) and collimators. The Si(Li) detector (Ortec SLP-04160P-OPT-0.3 model) has 12.5 mm^2 active area, Be window thickness 0.8 µm and 160 eV FWHM at 5.9 keV. The preamplifier (239-POF model) is mounted on the head of the detector. Also, the Si(Li) detector is combined with 4096 channels MCA (DSPEC-LF model) and high voltage source 1000 V with negative polarity. The detector system energy calibration was conducted using the test radioactive sources. 13.92, 17.75, 20.78, 26.34 and 59.54 keV photon energies from the ^{241}Am point source (370 kBq activity) were used in the experiments. A narrow beam was desired for this experiment, so the radioactive point source was shielded by the pin hole lead collimators. The collimation was necessary to minimize the scattered radiation reaching the detector crystal and the measurements were taken in a narrow beam geometry setup with suitable collimators. The radioactive point source was fixed at a distance of 9 cm from the Be window of the detector. In minimizing the statistical uncertainty, the counting time with and without the food waste samples was selected between 15200 s and 61200 s. The life time which equals to real time was used in the MCA. The final intensity (I) and initial intensity (I_0) of the food waste samples were measured experimentally under the same timing and experimental conditions. The corresponding energy peak positions were checked before and after the experiments; and no shift was observed. Hence, we can conclude that the all detector systems are stable throughout the experiments. The corresponding peak areas were obtained with the help of the Origin 7.5 (demo) program. Using this program, the peak area corrections were performed by subtracting the background counts. A typical spectrum of ^{241}Am with and without attenuation by pomegranate peel sample is shown in Fig. 2.

2.3. Theoretical background

When a beam of photons with an initial intensity (I_0) passing through a certain medium, the beam is attenuated exponentially according to the Beer–Lambert law given by the following relation:

Table 1
Chemical composition of food wastes.

Sample	Density (g/cm^3)	Hydrogen (%)	Carbon (%)	Nitrogen (%)	Oxygen (%)
Pomegranate peel	1.362	5.438	43.345	0.565	50.652
Acorn cap	1.063	5.771	47.995	0.754	45.481
Lemon peel	1.181	3.457	26.410	0.909	69.224
Mandarin peel	1.250	5.928	44.628	1.099	48.345
Pumpkin peel	1.219	5.885	42.031	2.058	50.026
Grape peel	1.100	6.019	45.090	1.920	46.971
Orange peel	1.400	5.621	56.757	0.761	36.861
Pineapple peel	1.109	5.845	54.838	0.659	38.658
Acorn peel	1.350	5.537	47.349	1.346	45.767
Grape stalk	1.368	5.923	44.397	1.765	47.915

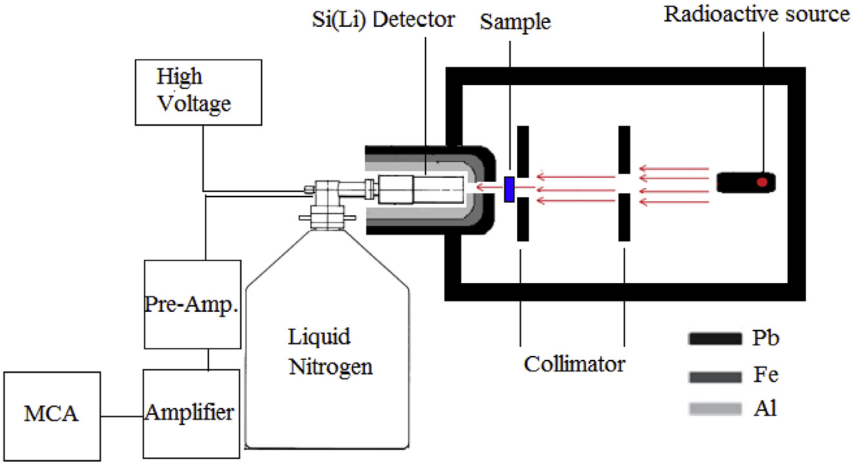

Fig. 1. Transmission geometry.

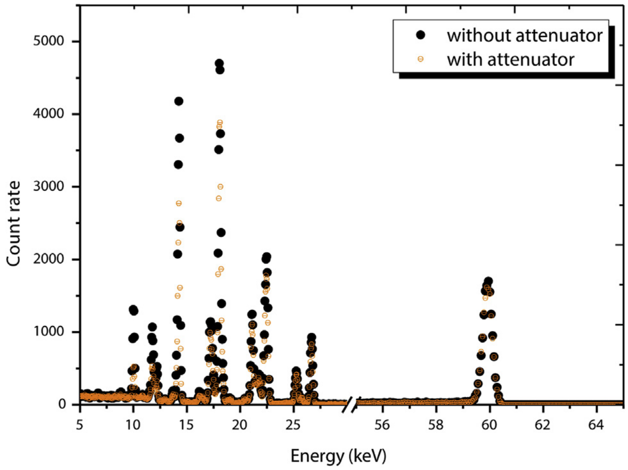

Fig. 2. A typical spectrum of ^{241}Am with and without attenuation by pomegranate peel sample.

$$I = I_0 e^{-\mu x} \tag{1}$$

where I, I_0, x and μ represent the transmitted intensity, initial intensity from the source, the thickness of the medium and the linear attenuation coefficient of the medium, respectively. One important parameter related to μ is the mass attenuation coefficients (μ/ρ) which measures the probability of the interaction that occurs between the gamma photon and the medium.

The theoretical values for the μ/ρ for all elements as well as for different mixtures and compounds are available in different standard tables [15]. The theoretical values of the present samples can be calculated from the sum of weighted contributions from the constituent elements (H, C, N and O). This method is known as mixture rule and can be written as [16]:

$$\left(\mu/\rho\right)_{\text{sample}} = \sum_i w_i \left(\mu/\rho\right)_i \tag{2}$$

where w_i represents the weight fraction, $(\mu/\rho)_i$ the mass attenuation coefficient of the i^{th} (H, C, N and O) elements. Theoretical $(\mu/\rho)_i$ values of the present samples were predicted from WinXCOM [17].

The effective atomic number (Z_{eff}) can be obtained from the knowledge of μ/ρ by using the following equation:

$$Z_{eff} = \frac{\sum_i f_i A_i (\mu/\rho)_i}{\sum_j f_j \frac{A_j}{Z_j} (\mu/\rho)_j} \tag{3}$$

where f_i is the fractional abundance of the element i relative to the number of atoms, Z_i is the atomic number and A_i is the atomic weight. The more detailed knowledge of determination of effective atomic number is given in Refs. [18–20].

The effective electron density (N_E) is another important quantity that characterizes the number of electrons per unit mass of the interacting materials. The N_E is related to the Z_{eff} according to the following relation [21]:

$$N_E = N_A \frac{n_{tot} Z_{eff}}{\sum_i n_i A_i} \tag{4}$$

where n_{tot} is the total number of atoms, n_i is the atom number of ith element, A_i is the atomic weight of ith element and N_A is the Avogadro constant.

The molar extinction coefficient (ε) is the attenuation produced by one mole of the substance. Singh and Gerward [22] showed that the molar extinction coefficient can be calculated from the μ/ρ values by using the following relation:

$$\varepsilon = 0.4343 M (\mu/\rho) \tag{5}$$

where M is the molecular weight.

3. Results and discussion

Table 1 presents the main abundant elements of the food wastes. These values helped us to calculate the theoretical μ/ρ values using WinXCOM program for the selected samples at different energies. Mass attenuation coefficients (μ/ρ) of pomegranate peel, acorn cap, lemon peel, mandarin peel, pumpkin peel, grape peel, orange peel, pineapple peel, acorn peel and grape stalk were measured at photon energies - 13.92, 17.75, 20.78, 26.34 and 59.54 keV - together with the theoretical values evaluated utilizing mixture rule from WinXCOM program have been illustrated in Table 2. The mass attenuation coefficients of lemon, mandarin, and pineapple peels as a function of photon energy are given in Fig. 3 to better observe changes in experimental and theoretical mass attenuation coefficient results. The mass attenuation coefficients of other food waste samples are also in the same trend. It is apparent from Table 2 and Fig. 3 that the experimentally measured μ/ρ values

Table 2
Experimental and theoretical values of mass attenuation coefficient (cm^2/g) for food wastes.

Sample	13.92 keV		17.75 keV		20.78 keV		26.34 keV		59.54 keV	
	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.
Pomegranate peel	1.6700 ± 0,0347	1.5950	0.8201 ± 0.0389	0.8568	0.6312 ± 0.0128	0.6022	0.3756 ± 0.0112	0.3899	0.1868 ± 0,0052	0.1920
Acorn cap	1.5922 ± 0.0474	1.5301	0.8687 ± 0.0393	0.8264	0.6053 ± 0.0130	0.5838	0.3782 ± 0.0126	0.3812	0.1856 ± 0,0056	0.1917
Lemon peel	1.9262 ± 0.0624	1.8503	0.9480 ± 0.0523	0.9754	0.6982 ± 0.0115	0.6739	0.4004 ± 0.0154	0.4226	0.1873 ± 0.0074	0.1919
Mandarin peel	1.5028 ± 0.0841	1.5721	0.8590 ± 0.0568	0.8464	0.5820 ± 0.0271	0.5962	0.3730 ± 0.0268	0.3873	0.2028 ± 0.0120	0.1924
Pumpkin peel	1.6206 ± 0.0609	1.5861	0.8649 ± 0.0510	0.8530	0.6274 ± 0.0153	0.6003	0.4046 ± 0.0108	0.3893	0.1971 ± 0.0052	0.1926
Grape peel	1.5104 ± 0.0242	1.5532	0.8126 ± 0.0261	0.8374	0.6169 ± 0.0291	0.5906	0.3643 ± 0.0084	0.3847	0.1818 ± 0.0038	0.1922
Orange peel	1.4459 ± 0.0886	1.4139	0.7623 ± 0.0660	0.7714	0.5429 ± 0.0175	0.5499	0.3479 ± 0.0237	0.3648	0.1925 ± 0.0119	0.1901
Pineapple peel	1.3701 ± 0.0423	1.4366	0.8293 ± 0.0468	0.7823	0.5379 ± 0.0119	0.5567	0.3746 ± 0.0107	0.3683	0.1834 ± 0.0051	0.1907
Acorn peel	1.4694 ± 0.0661	1.5391	0.8579 ± 0.0564	0.8304	0.5591 ± 0.0130	0.5860	0.3759 ± 0.0238	0.3821	0.2018 ± 0.0085	0.1914
Grape stalk	1.5322 ± 0.0591	1.5697	0.8017 ± 0.0498	0.8453	0.6131 ± 0.0116	0.5955	0.3756 ± 0.0229	0.3871	0.1874 ± 0.0078	0.1925

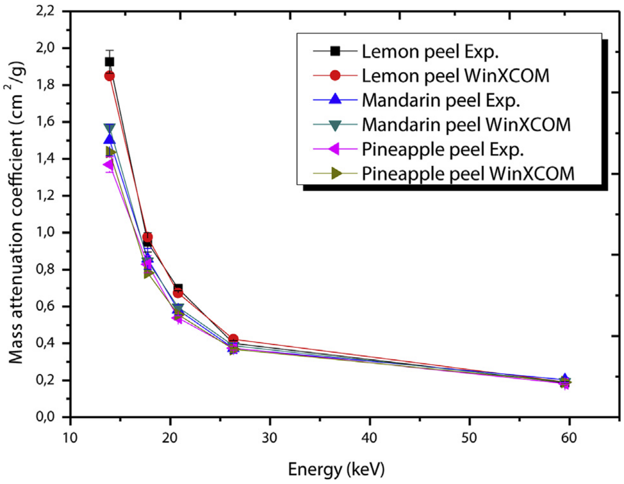

Fig. 3. The mass attenuation coefficients of lemon, mandarin, and pineapple peels as a function of photon energy.

were in good agreement with those calculated theoretically. This agreement between the experimental and theoretical μ/ρ values supports the validity of the transmission geometry used for determining μ/ρ for the present food waste samples.

Inspection of the data in Table 2 and Fig. 3 shows that the μ/ρ values of the food waste samples decreases exponentially with the increase of photon energy. Besides, lemon peel has higher values of μ/ρ among the selected food waste samples, due to higher amount of oxygen in this sample. Also, Table 2 shows that μ/ρ values for the lowest photon energy (13.92 keV) present higher difference between the food waste samples in relation to μ/ρ values for the highest photon energy (59.54 keV), where the μ/ρ values at 59.54 keV for all samples are almost the same. This is because at low photon energies, variances in chemical composition affect remarkably the attenuation of a certain sample.

The experimental uncertainty in the measurement of μ/ρ values was evaluated from the following relation [23]:

$$\Delta\left(\frac{\mu}{\rho}\right) = \frac{1}{\rho x}\sqrt{\left(\frac{\Delta I_0}{I_0}\right)^2 + \left(\frac{\Delta I}{I}\right)^2 + \left(\ln\frac{I_0}{I}\right)^2 \cdot \left(\frac{\Delta \rho x}{\rho x}\right)^2} \tag{6}$$

where x, ρ are the thickness and density of the sample, ΔI_0 and ΔI represent the uncertainties of I_0 and I, and ρx represents the uncertainty in the mass per unit area.

Using Eq. (6), the uncertainty in the experimental

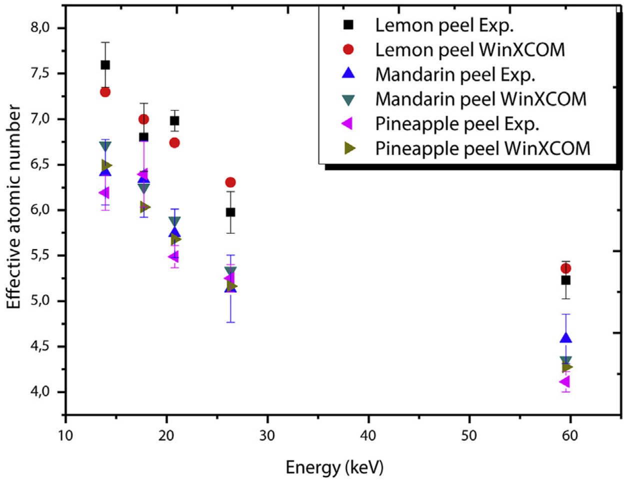

Fig. 4. A typical graph of effective atomic numbers for lemon, mandarin and pineapple peels as a function of photon energy.

Table 3
Experimental and theoretical values of effective atomic number for food wastes.

Sample	13.92 keV		17.75 keV		20.78 keV		26.34 keV		59.54 keV	
	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.
Pomegranate peel	7.102 ± 0.147	6.783	6.071 ± 0.288	6.343	6.283 ± 0.128	5.995	5.260 ± 0.157	5.460	4.360 ± 0.121	4.482
Acorn cap	6.928 ± 0.206	6.658	6.520 ± 0.295	6.203	6.063 ± 0.130	5.847	5.271 ± 0.176	5.313	4.226 ± 0.127	4.364
Lemon peel	7.595 ± 0.246	7.296	6.799 ± 0.375	6.996	6.982 ± 0.115	6.739	5.974 ± 0.229	6.304	5.230 ± 0.206	5.359
Mandarin peel	6.416 ± 0.359	6.712	6.341 ± 0.420	6.248	5.745 ± 0.268	5.885	5.137 ± 0.370	5.335	4.585 ± 0.272	4.352
Pumpkin peel	6.878 ± 0.258	6.731	6.353 ± 0.375	6.266	6.168 ± 0.151	5.901	5.557 ± 0.149	5.348	4.456 ± 0.118	4.356
Grape peel	6.490 ± 0.104	6.674	6.007 ± 0.193	6.191	6.074 ± 0.286	5.815	4.976 ± 0.115	5.253	4.034 ± 0.083	4.265
Orange peel	6.613 ± 0.405	6.466	5.947 ± 0.515	6.019	5.604 ± 0.180	5.677	4.933 ± 0.336	5.173	4.363 ± 0.270	4.309
Pineapple peel	6.191 ± 0.191	6.491	6.394 ± 0.361	6.032	5.489 ± 0.122	5.681	5.252 ± 0.150	5.164	4.113 ± 0.114	4.276
Acorn peel	6.389 ± 0.287	6.692	6.457 ± 0.424	6.250	5.633 ± 0.131	5.904	5.292 ± 0.335	5.379	4.677 ± 0.197	4.436
Grape stalk	6.544 ± 0.252	6.704	5.915 ± 0.367	6.237	6.045 ± 0.115	5.872	5.163 ± 0.314	5.320	4.222 ± 0.175	4.337

Table 4
Experimental and theoretical values of effective electron density ($x10^{25}$) (electrons/g) for food wastes.

Sample	13.92 keV		17.75 keV		20.78 keV		26.34 keV		59.54 keV	
	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.
Pomegranate peel	1.720 ± 0.036	1.643	1.471 ± 0.070	1.536	1.522 ± 0.031	1.452	1.274 ± 0.038	1.322	1.056 ± 0.029	1.086
Acorn cap	1.300 ± 0.039	1.250	1.224 ± 0.055	1.164	1.138 ± 0.024	1.097	0.989 ± 0.033	0.997	0.793 ± 0.024	0.819
Lemon peel	0.944 ± 0.031	0.907	0.845 ± 0.047	0.870	0.868 ± 0.014	0.838	0.743 ± 0.028	0.784	0.650 ± 0.026	0.666
Mandarin peel	0.834 ± 0.047	0.872	0.824 ± 0.055	0.812	0.746 ± 0.035	0.765	0.667 ± 0.048	0.693	0.596 ± 0.035	0.565
Pumpkin peel	0.474 ± 0.018	0.464	0.438 ± 0.026	0.432	0.425 ± 0.010	0.407	0.383 ± 0.010	0.369	0.307 ± 0.008	0.300
Grape peel	0.484 ± 0.008	0.498	0.448 ± 0.014	0.462	0.453 ± 0.021	0.434	0.371 ± 0.009	0.392	0.301 ± 0.006	0.318
Orange peel	1.236 ± 0.076	1.208	1.111 ± 0.096	1.125	1.047 ± 0.034	1.061	0.922 ± 0.063	0.967	0.815 ± 0.050	0.805
Pineapple peel	1.351 ± 0.042	1.416	1.395 ± 0.079	1.316	1.197 ± 0.027	1.239	1.146 ± 0.033	1.126	0.897 ± 0.025	0.933
Acorn peel	0.661 ± 0.030	0.692	0.668 ± 0.044	0.647	0.583 ± 0.014	0.611	0.547 ± 0.035	0.556	0.484 ± 0.020	0.459
Grape stalk	0.530 ± 0.020	0.543	0.479 ± 0.030	0.505	0.490 ± 0.009	0.476	0.418 ± 0.025	0.431	0.342 ± 0.014	0.351

measurements was found to be less than 7%. This uncertainty is mostly due to the scattered photons reaching the detector, the thickness and density measurements, and statistical uncertainties in I and I_0.

Experimental as well as theoretical Z_{eff} values were summarized in Table 3. Also, in this table we presented the experimental uncertainties in Z_{eff} values. A typical graph of effective atomic numbers for lemon, mandarin and pineapple peels as a function of photon energy is exhibited in Fig. 4. Satisfactory agreement has been reported between experimentally measured as well as theoretically calculated values. Besides, it is clear from Table 3 that the Z_{eff} values of all food wastes lie within range of 4.034–7.595 for studied energy region. This means that the Z_{eff} for the present food waste samples remain in the range of the atomic number (Z) of the constituent elements of these samples, namely H, C, N and O ($1 < Z_{eff} < 8$). Furthermore, from Table 3 it can be obviously noticed that the Z_{eff} values for all samples under investigation change very little since all these samples consist of low Z constituent elements. Again, we found that the lemon peel has the highest values of Z_{eff} among the selected samples, due to its relatively high value of mass attenuation coefficients in comparison with other samples. Also, from Table 3 and Fig. 4, it is found that the Z_{eff} values decrease with the increase of photon energy. The trend of Z_{eff} with photon energies is nearly identical to that of μ/ρ. The experimental and theoretical Z_{eff} values then were used to calculate the electron density (N_E) for the present food waste samples and the results have been depicted in Table 4. To observe the change, the effective electron densities of lemon, mandarin and pineapple peels were plotted versus photon energy as seen Fig. 5. The N_E of the studied food wastes is found to be in the range of 0.301–1.720 × 10^{25} (electrons/g) for studied energy region. Additionally, the trend of N_E with photon energy is almost similar to that of Z_{eff}.

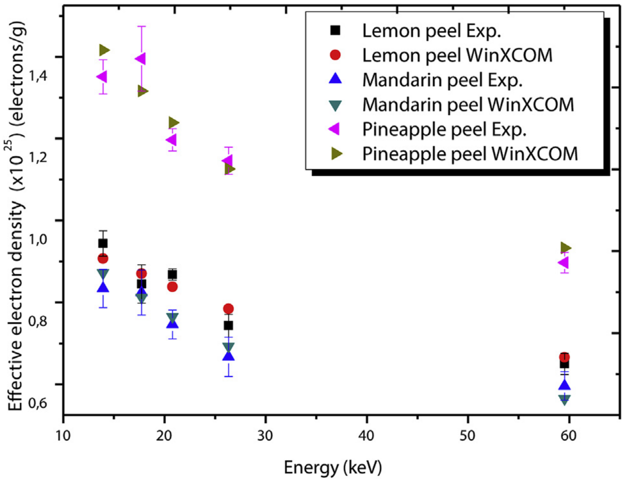

Fig. 5. The effective electron densities of lemon, mandarin and pineapple peels versus photon energy.

The molar extinction coefficient is a common parameter when dealing with the attenuation of a photon through certain medium. The experimental and theoretical values of ε for the present food waste samples are enlisted in Table 5. Also, the typical plot of molar extinction coefficients versus photon energy for lemon, mandarin and pineapple peels is shown in Fig. 6. There is an agreement between the experimentally measured ε values with those obtained theoretically using WinXCOM program. It is clearly seen from the values in Table 5 and Fig. 6 that the values of ε for all samples depend inversely upon the energy of the photon. In other words, the behavior of ε with photon energies is similar to that of μ/ρ and this is logical since ε depends on μ/ρ according to Eq. (5).

Table 5
Experimental and theoretical values of molar extinction coefficients for food wastes.

Sample	13.92 keV		17.75 keV		20.78 keV		26.34 keV		59.54 keV	
	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.
Pomegranate peel	1789 ± 37	1708	878 ± 42	918	676 ± 14	645	402 ± 12	418	200 ± 6	206
Acorn cap	1285 ± 38	1234	701 ± 32	667	488 ± 10	471	305 ± 10	308	150 ± 5	155
Lemon peel	1295 ± 42	1244	637 ± 35	656	469 ± 8	453	269 ± 10	284	126 ± 5	129
Mandarin peel	834 ± 47	873	477 ± 32	470	323 ± 15	331	207 ± 15	215	113 ± 7	107
Pumpkin peel	478 ± 18	467	255 ± 15	251	185 ± 5	177	119 ± 3	115	58 ± 2	57
Grape peel	471 ± 8	485	254 ± 8	261	193 ± 9	184	114 ± 3	120	57 ± 1	60
Orange peel	1152 ± 71	1127	607 ± 53	615	433 ± 14	438	277 ± 19	291	153 ± 9	151
Pineapple peel	1261 ± 39	1322	763 ± 43	720	495 ± 11	512	345 ± 10	339	169 ± 5	175
Acorn peel	666 ± 30	698	389 ± 26	376	253 ± 6	266	170 ± 11	173	91 ± 4	87
Grape stalk	528 ± 20	541	276 ± 17	291	211 ± 4	205	129 ± 8	133	65 ± 3	66

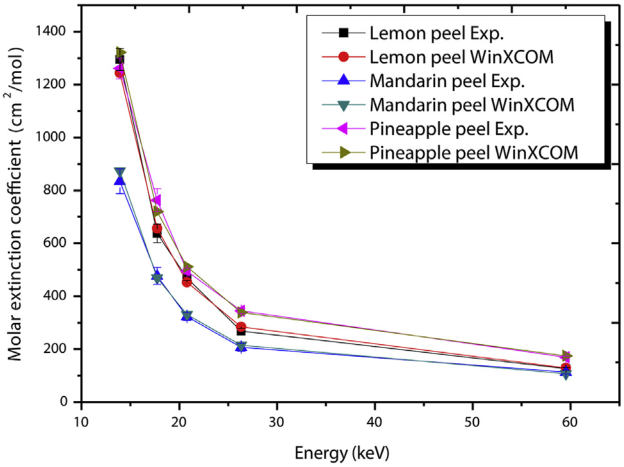

Fig. 6. The typical plot of molar extinction coefficients versus photon energy for lemon, mandarin and pineapple peels.

4. Conclusion

The experimental work in this study was aimed to get some information on the μ/ρ for ten food waste samples at 13.92, 17.75, 20.78, 26.34 and 59.54 keV. The results revealed that the μ/ρ is a useful quantity to compute some other quantities such as Z_{eff}, N_E and ε for the selected food wastes. All the measured parameters were compared with the theoretical values calculated by WinXCOM program and good agreement between the measured and calculated values was reported. The lemon peel sample has the highest values of μ/ρ as well as Z_{eff}. For all selected samples the variation of N_E with photon energy is almost identical to Z_{eff}. The obtained results in this investigation can stimulate the experimental and theoretical research for other types of food waste samples. The results obtained from the present investigation aimed to discover the potential of food wastes as a candidate radiation shielding materials and guide a different area for their recycling. Also, this work can be useful in the design of new industrial radiation shielding products using waste foods and in the development of non-toxic shielding materials.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.net.2018.05.007.

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