



Rapid detection of the adulterants in milk using gamma radiation

Manali Chakraborty^a, Savita Budhwar^{a,*}, Suneel Kumar^b

^a Department of Nutrition Biology, Central University of Haryana, Mahendergarh, Jant- Pali, Haryana, 123029, India

^b Department of Physics and Astrophysics, Central University of Haryana, Mahendergarh, Jant- Pali, Haryana, 123029, India

ARTICLE INFO

Keywords:

Milk adulteration
Synthetic milk
Milk-protein coagulation
Gamma irradiation
Cesium-137

ABSTRACT

Milk and dairy adulteration practice nowadays is becoming a global concern. The present study discloses the role of gamma irradiation as a cost-effective and rapid-detection approach to detect adulterants in milk instead of using expensive and time-consuming chemical-based methods. In the present study, synthetic milk samples were prepared using different common adulterants (vegetable oil, urea, water) and a comparative analysis has been done with market milk samples along with fresh milk based upon the attenuation property. The obtained linear attenuation coefficient decreases significantly ($p < 0.05$) with the increasing concentration of adulterants in sample. The recorded attenuation coefficient for fresh milk was 0.379 ± 0.04 and that of adulterated samples found to be in the range of 0.296–0.188. Moreover, different protein coagulation patterns of the heat-processed milk samples were detected. The coagulated protein of adulterated milk shows a granular texture. The attenuation coefficient of milk samples decreases with the gradual increase of adulterants. The correlation between the attenuation coefficient and adulterants in milk indicated the possible use of gamma radiation as a significant adulterant-detection method.

1. Introduction

India is one of the highest milk production countries (annual production of around 127 million tons) worldwide according to NDDB (National Dairy Development Board) (2013) [1]. Naturally milk is obtained from lacteal secretion by complete milking which contains definite percentages of fat, protein, solids. However, due to its health benefits, the increasing demand for milk production is leading to the malpractice of synthetic milk production. Addition of the adulterants to natural milk and manipulation of the available nutrients is creating serious concern for health upon consumption. Although several methods viz., determination of fat and solids, freezing point, bacterial count etc. are available to detect the added chemicals like vegetable oil, urea, detergent etc. in the milk [1], the determination procedures are expensive and time consuming [1]. According to Indian Council of Medical Research (ICMR) report, addition of such foreign elements in milk can show hazardous effect on human health resulting in impairment of biological systems over the time. The most common difference in the properties of synthetic and natural milk is that on rubbing on the palm, synthetic milk produces foam like appearance. pH of the synthetic milk is also highly alkaline (pH 10–11) in comparison with natural milk (pH 6.6–6.8) which is almost neutral in nature. On heating in case of

synthetic milk, the colour of milk turns to pale yellow after sometimes. Whereas, under the similar conditions the colour of natural milk remains the same [2]. Presence of different adulterants in the synthetic milk changes the primary composition of milk. Component like urea is used as non-protein nitrogen (NPN) source to prepare synthetic milk to increase the milk solid not fat (SNF) content to get the thick and concentrated texture [3]. Presence of NPN also increases the protein value as it is measured based on nitrogen content. According to the Expert committees from World Health Organization (WHO) and Food and Drug Administration (FDA) toxicity of adulterants, crystal formation due to added elements can lead to blockage of renal tubes resulting in the kidney functioning failure [4–6].

Besides health concern, storage stability of the milk is also a major concern [7]. In comparison with natural milk, adulterated milk shows longer shelf life due to presence of added urea, detergent, vegetable oil etc. Presence of urea is responsible for the alkaline pH of synthetic milk. This elevated urea concentration prevents aggregation as well as precipitation of milk protein and leads to stabilization of the protein resulting in longer shelf life [8,9]. This is also one of the reasons the practice of production of synthetic milk in market is increasing day by day. Milk is considered as an essential food for daily healthy diet in everyday life [10,11] as it is a rich source of calcium, protein, minerals,

* Corresponding author.

E-mail addresses: manalich2@gmail.com, manali11073@cuh.ac.in (M. Chakraborty), savitadahya@cuh.ac.in (S. Budhwar), suneelkumar@cuh.ac.in (S. Kumar).

<https://doi.org/10.1016/j.jafr.2023.100595>

Received 8 December 2022; Received in revised form 21 April 2023; Accepted 22 April 2023

Available online 4 May 2023

2666-1543/© 2023 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

carbohydrates, fat and essential vitamins [12,13]. Addition of urea, starch, ammonium, sulphate, salt, water and milk powder to natural milk increase the volume and viscosity of milk [14]. Chemical preservatives viz., formalin are also added in milk to enhance storage stability [15,16] with adverse health effects. Therefore, as a replacement to the available adulteration detection methods, the role of radiation to identify the presence of added constituents is being explored intensively (Udagani and Ramesh 2014). The study of diffusion and penetration of gamma radiation in the external medium to understand the interaction of radiation with matter can be advantageous for several applications in the field of food science and human health [17].

Adulteration of food products using cheaper and harmful substitutes is a crucial problem faced by the society. A study mentioned mixing of cheaper solvent, diethylene glycol in alcohol based beverages to enhance sweetness which indirectly reduce the cost [18,19]. Depending on the level of consumption of toxic adulterants over time, effect of such adulterants on health can be graded [20–22]. In previous study, gamma ray spectroscopic method was used to detect such adulterants based upon the alteration in linear and mass attenuation coefficients. Although gamma ray spectroscopy method is more popular in nuclear science research, the study of interaction of gamma radiation with solid food products or liquid products like juice, milk etc. can depict significant information about the chemical composition of the provided sample. The linear attenuation coefficient and mass absorption coefficient depends on the energy of the incident gamma radiation and the chemical composition of the sample [23]. The linear attenuation coefficients of potassium chloride, ammonium chloride, ferrous sulphate, carbohydrates, phenol, urea and lactose in milk at different concentrations had been studied using gamma ray spectroscopic technique [24–30]. The detection and quantitative estimation of adulteration like melamine content in milk powder using gamma ray spectroscopy (Udagani and Ramesh 2014) also had been reported. According to the obtained data, linear attenuation coefficient increases with increase in the melamine content in milk powder.

Instead of using expensive analytical techniques, gamma irradiation technology can play a key role to detect adulterants in milk based upon the radiation attenuation property of the same in a cost-effective way [31]. The attenuation coefficient is basically the measurement by which absorption of incident energy beam through a material can be studied. Due to presence of definite elements, exposed gamma radiation either get absorbed in the sample or scattered in certain manner and escape. The behaviour of gamma radiation is different for different elements. Hence, it is essential to explore the use of gamma radiation as an alternative and nondestructive technique, free from the usage of other reagents to detect the presence of adulterants [32]. Therefore, comparative study to estimate attenuation co-efficient from synthetic milk and natural milk can be helpful further to detect the adulteration in milk.

Hence based on the literature survey, the present study has two fold objectives: To understand the role of gamma radiation for the detection of adulterants present in milk samples by comparing the obtained attenuation coefficient. The storage stability of adulterated milk samples, commercial milk and natural milk along with the effect of heat treatment and gamma radiation exposure to the milk protein coagulation pattern have been analyzed as well.

2. Materials and methods

In the present study, the detection of presence of adulterants in milk samples has been performed by designing untargeted model instead of screening particular adulterant using targeted model. Untargeted model detects nonspecific deviations in the attenuation coefficient of the milk samples.

Double toned milk samples (Milk brand 1,2,3) had been procured from the local market of Mahendergarh, Haryana. Fresh milk was collected from the breed Murrah buffalo of local village of

Mahendergarh and time of milking was 5.00 a.m. Fat and protein analysis of the raw samples (without boiling) were determined followed by Soxhlet and Kjeldahl method [33] respectively. The process of sample processing was carried out in the laboratory of 'Department of Nutrition Biology', Central University of Haryana, India. Further proceedings of irradiating milk samples to gamma source and detection of gamma radiation in the samples were carried out in the 'Department of Physics and Astrophysics', Central University of Haryana, India.

¹³⁷Cs gamma source was preferred to determine the radiation attenuation property of different milk samples using GM counter. The calibration of detector was performed using test radioactive source. The counting time with and without absorber was set to 90 s in order to minimize statistical error, Counting timing, and other experimental conditions were kept same to obtain initial and final intensity. The attenuation coefficient of any food item is the reflection of its internal structure. The quantity of energy absorbed by any food item is related to their attenuation coefficient. Hence small value of linear attenuation coefficient indicate that material is transparent, while a larger value of attenuation coefficient indicates greater opacity [34]. The measured intensity (I) of transmitted gamma ray through a layer of material with thickness (t) is related to intensity of incident radiation as $I = I_0 e^{-\mu t}$, where t is path length and μ (cm^{-1}) is the attenuation coefficient.

The experiment was carried out in two phases. In first phase, pure buffalo milk sample was taken and known amount of adulterants were added to imitate the synthetic milk composition. Pure milk sample was distributed into six groups in below mentioned manner (Table 1).

These prepared imitated milk samples were exposed to gamma source (¹³⁷Cs having present day activity 0.3477 μCi) for 24 h, 48 h and 72 h stored at room temperature ($25 \pm 2^\circ\text{C}$) to study the effect of gamma radiation on the storage stability of the samples. Attenuation co-efficient of the same was also determined using the same source.

In the second phase of the experiment, collected market milk samples were exposed to radiation from ¹³⁷Cs followed by determination of attenuation co-efficient and effect of gamma radiation on the milk samples. Results obtained from both the phases were compared to understand the role of gamma radiation in the detection of adulterants in milk sample.

During the storage of the treated prepared imitated milk samples and the market milk samples at room temperature, upon spoilage, the

Table 1
Preparation of imitated sample compositions.

Samples	Type of adulterants added	Preparation of mixture	Total volume of the final mixture sample taken
sample + Vegetable oil+ 1 gm urea	Vegetable oil, water and urea	20 ml of luke warm water was added to 20 ml pure milk. 1 ml vegetable oil and 1 g urea were added to the mixture	40 ml
sample + Vegetable oil +0.5 gm urea	Vegetable oil, water and urea	20 ml of luke warm water was added to 20 ml pure milk. 1 ml vegetable oil and 0.5 g urea were added to the mixture	
sample+ 1 gm urea	Urea and water	20 ml of luke warm water was added to 20 ml pure milk. 1 g urea was added to the mixture	
sample+0.5 g urea	Urea and water	20 ml of luke warm water was added to 20 ml pure milk. 0.5 g urea was added to the mixture	
sample + gluten	Gluten and water	20 ml of luke warm water was added to 20 ml pure milk. 1 g gluten was added to the mixture	
sample	–	–	

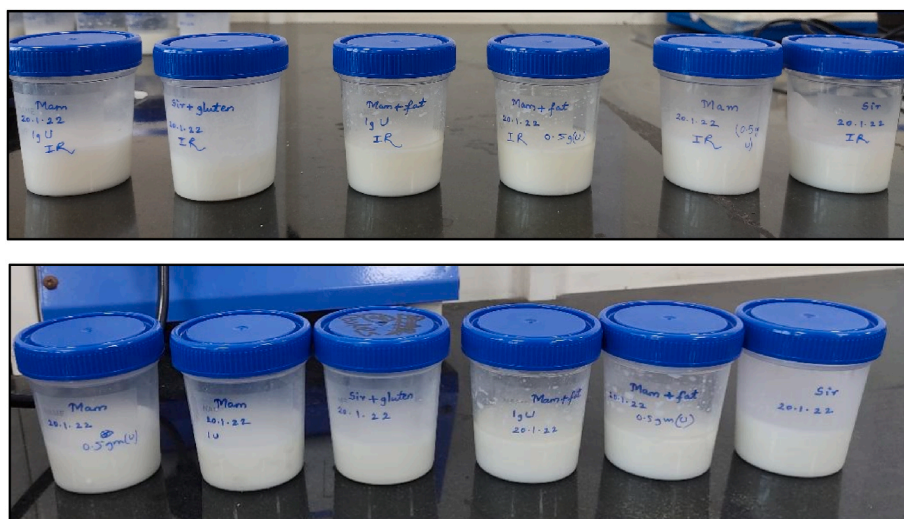


Fig. 1. Milk sample prepared using known amount of adulterants (Urea, Gluten, vegetable oil and water were added to the fresh buffalo milk, collected from village to imitate the composition of adulterated or commercial milk samples for further analysis).

samples were given heat treatment (at 100 °C using hot plate for 2 min) to observe the structure variance of heat-induced curdled milk (mass particles) due to protein coagulation. Pattern variance of obtained coagulated milk protein (heat-induced curdled milk) due to influence of adulterants and radiation treatment on parent milk samples were also studied (Fig. 1).

2.1. Statistical analysis

The data obtained from fat and protein analysis of the milk samples (evaluated in triplicates) were subjected to analysis of variance using MS Office Excel (2016) where the estimated data were presented as means $\pm$ standard error. Assessment of the statistical significance was carried out by using one-way analysis of variance (ANOVA) followed by Tukey HSD Test ($p < 0.05$).

3. Results and discussions

The present study disclosed the correlation between attenuation coefficient and composition of different milk samples. Milk with greater density showed larger value of attenuation coefficient and vice versa. Fresh milk, collected from village, attenuated more gamma radiation in comparison to adulterated milk samples, prepared in laboratory. Decrease in the value of mass attenuation coefficient of the adulterated milk samples indicates higher photon interaction probability at lower energy [35]. Based upon the obtained data of the imitated milk samples (prepared in lab), attenuation coefficient of pure milk sample was the highest (Table 2). The linear attenuation coefficient of pure milk sample was 0.379 and mass attenuation of the same was 0.360. In case of imitated milk samples, sample containing gluten showed lesser attenuation coefficient than the pure milk sample. The attenuation coefficient value decreased with the increasing concentration of added urea in the milk sample. Upon adding vegetable oil along with urea in the milk sample, attenuation coefficient decreased even more. Sample containing fat and 1 g urea showed least attenuation co-efficient value (Fig. 2) which was 0.188. Decrease in the attenuation property of the adulterated milk samples might be responsible for decreasing viscosity due to presence of adulterants like urea. According to a study by Ref. [36]; though urea enhances the stability, it also decreases the viscosity of solution (see Fig. 3) (see Table 3).

Followed by the determination of attenuation property, the milk samples were exposed to gamma source (^{137}Cs) for 24 h and stored at room temperature (25 ± 2 °C) in plastic containers. The lids of containers were left open. Present counts in the irradiated samples were estimated by the interval of 24 h. According to the estimated data, all the sample showed zero radiation count on third day. Spoilage of milk occurs due to excess growth of microorganism resulting in production of lactic acid. Increasing acidity of milk leads to coagulation of milk protein, forming soft lumps. Upon heating milk protein becomes over saturated and gain visible curdling. Hence, upon obtaining zero radiation count of the exposed samples, they were boiled to check whether the samples got spoiled or still retaining required consumable quality. Exposed pure sample and sample with gluten exhibited bit sour smell with visible protein coagulation on the third day. Rest exposed samples containing urea and vegetable oil showed sour smell indicating spoilage on seventh day. Besides determination of storage stability, effect of radiation on milk protein coagulation were also noted. Upon boiling of the samples, irradiated pure sample showed larger sized solid particle/curdled mass in comparison with that of gluten containing irradiated sample.

Irradiated urea and fat containing samples showed smaller size of solid particles/curdled mass with granular texture. Increase in the concentration of urea in milk sample resulted in visible effect on coagulated particles in sample. Irradiated milk sample containing 0.5 g urea showed smaller grains of coagulated milk protein (curdled mass). Moreover, irradiated milk sample containing 1 g urea showed fine granular texture of coagulated milk protein. The observed analysis depicted inversely proportional relation of coagulated milk protein texture with the concentration of added adulterant like urea. Non-irradiated pure sample and gluten containing sample showed spoilage on third day.

Upon heating larger sized lumps of coagulated milk protein was observed in case of spoiled non-radiated pure milk. Curdled lump obtained from non-irradiated gluten containing sample was smaller than the unadulterated milk. Non-irradiated urea and fat containing samples showed spoilage on sixth day. The obtained observation depicted that the implication of gamma radiation to the milk sample might cause obstacle to the excessive growth of lactic acid producing bacteria, resulting in balance of pH of milk samples and their storage stability. Spoiled urea containing samples showed smaller grains of coagulated

Table 2

Attenuation co-efficient of prepared milk samples containing different adulterants.

Samples	Nb (Background radiation count)	Nc (Radiation count)	Height of milk samples (cm)	Density	Linear attenuation	Mass attenuation
sample + Vegetable oil + 1 gm urea	31	122 ± 0.03 ^a	2.5	1	0.188 ± 0.32 ^d	0.188 ± 0.31 ^d
sample + Vegetable oil + 0.5 gm urea		119 ± 0.15 ^b	2.5	1	0.201 ± 0.18 ^c	0.201 ± 0.05 ^d
sample+ 1 gm urea		105 ± 0.22 ^c	2.5	1.026	0.279 ± 0.05 ^c	0.272 ± 0.01 ^{bc}
sample+0.5 g urea		101 ± 1.05 ^d	2.5	1.026	0.302 ± 0.01 ^b	0.294 ± 0.12 ^b
Sample + gluten		102 ± 0.01 ^d	2.5	1.026	0.296 ± 0.02 ^{ab}	0.288 ± 1.08 ^c
sample (pure)		90 ± 0.14 ^{cd}	2.5	1.053	0.379 ± 0.04 ^a	0.360 ± 0.09 ^a

Note: Data presented are radiation counts in the exposed imitated milk samples. significantly different, $p < 0.05$ (Statistical analysis has been done row wise).

Table 3

Observed radiation counts in gamma irradiated milk samples.

	24 h	48 h	72 h
sample + Vegetable oil + 1 gm urea	5 ± 0.01 ^c	3 ± 0.51 ^a	0
sample + Vegetable oil + 0.5 gm urea	7 ± 1.66 ^b	2 ± 0.45 ^b	0
sample+ 1 gm urea	2 ± 0.25 ^d	1 ± 0.11 ^c	0
sample+0.5 g urea	7 ± 0.16 ^{ab}	0	0
sample + gluten	9 ± 0.5 ^a	2 ± 0.19 ^{bc}	0
sample	9 ± 0.36 ^a	2 ± 0.41 ^{bc}	0

Note: Data presented are radiation counts in the exposed imitated milk samples. significantly different, $p < 0.05$ (Statistical analysis has been done row wise).

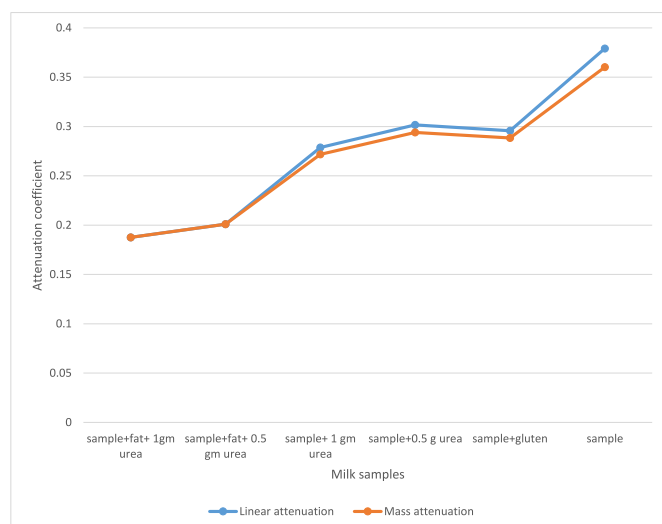


Fig. 2. Graphical representation of obtained attenuation co-efficient of imitated milk samples.

milk protein in comparison with that of unadulterated milk sample. Presence of fat in the milk also led to smaller grains of curdling. In comparison between irradiated and non-irradiated samples, size of curdled mass of coagulated milk protein obtained from radiated samples was smaller than that of non-irradiated samples. Smaller the size of curdled mass, more binding property was observed. A study by Ref. [37] showed enhanced binding property of starch with increased granulation.

Fat and protein percentages of the samples were also evaluated. Based upon the estimated data of the unadulterated milk and imitated milk samples, fat percentage (4.45%) was found highest in the sample containing fat and 1 g urea. Although among fat containing samples amount of added fat was same, due to presence of more urea, sample containing fat and 1 g urea might show more fat percentage (Figs. 4, 5 and 6). According to previous studies, it had been established that presence of urea in milk increase amount of solid-not fat (SNF) [3]. In case protein estimation, sample containing urea showed higher amount of protein percentages. Sample with only 1 g urea showed highest protein (3.91%). The samples with Vegetable oil +0.5 g urea and sample with 0.5 g urea showed 3.88% protein (Table 4 and 5).

After the characterization of different milk samples and their protein coagulation patterns, the attenuation property of the samples were evaluated. Obtained data of attenuation coefficient of the imitated milk samples disclosed a range of reference values indicating certain concentration of urea, vegetable oil, gluten and water present in milk. Further use of gamma radiation to check adulteration in commercial milk samples using these obtained reference values can be helpful to understand the added concentration of urea, vegetable oil, gluten in the tested sample in a cost effective way.

In the next phase of experimental design, each of 40 ml of procured commercial milk samples were taken for the analysis. Milk brand 3 showed highest attenuation coefficient and milk brand 2 showed least attenuation coefficient. The obtained attenuation co-efficient of market samples were similar to that of imitated milk samples containing urea, gluten, vegetable oil and water. Attenuation coefficient of milk brand 2 (0.2769) was approximately similar to that of imitated milk sample containing 1 g urea (0.2787). Attenuation coefficient of milk brand 1 was approximately similar to that of imitated milk sample containing

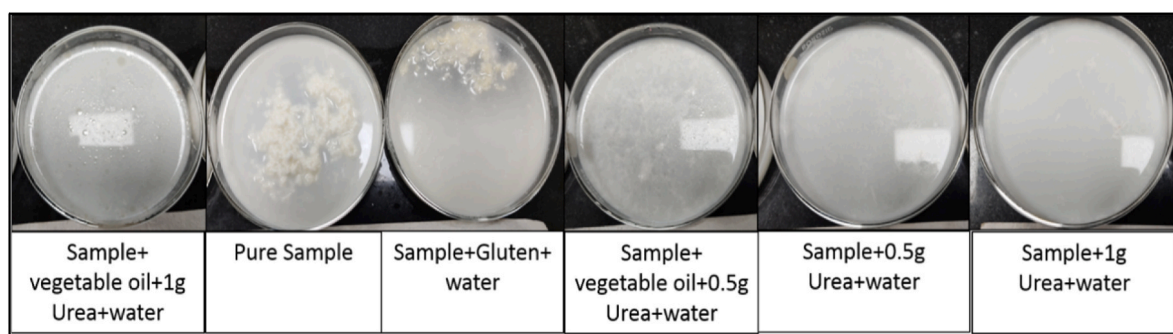


Fig. 3. Curdled mass/particle obtained from different composition of milk sample (not radiated) on boiling (Effect of the heat treatment to different milk protein coagulation patterns was observed).

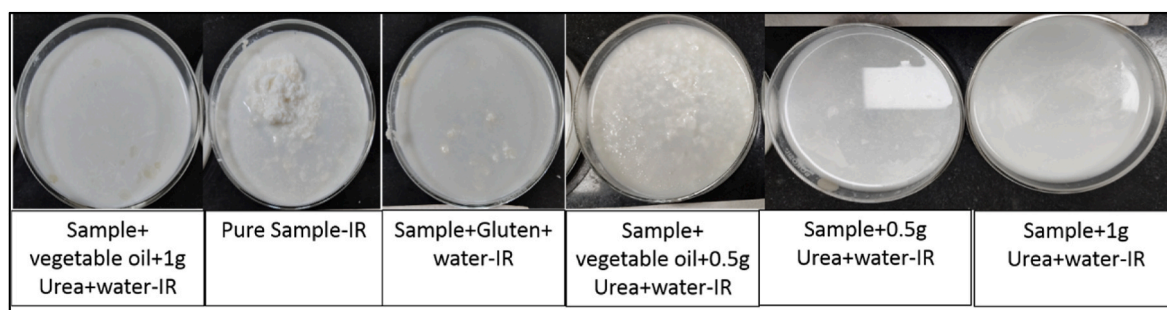


Fig. 4. Curdled mass/particle obtained from different composition of radiated milk sample on boiling (Effect of the heat treatment along with the gamma radiation exposure to different milk protein coagulation patterns was observed).

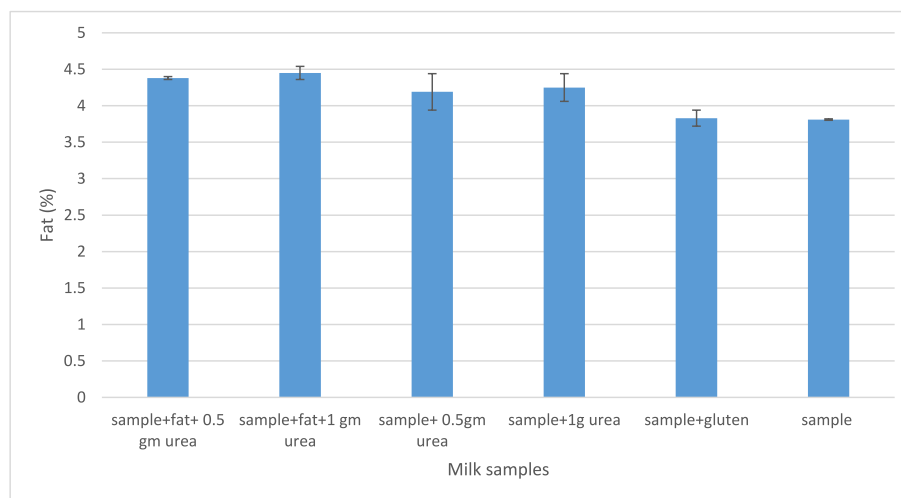


Fig. 5. Graphical representation of fat (%) present in imitated milk samples.

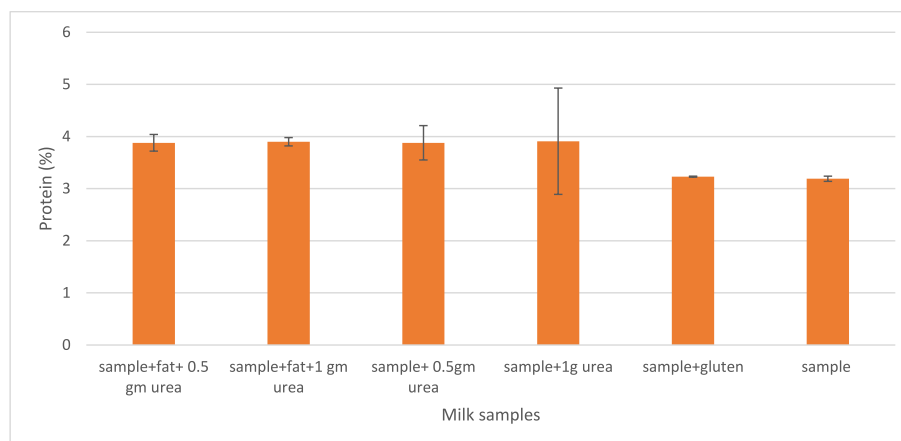


Fig. 6. Graphical presentation of protein (%) present in imitated milk samples (where the protein value was determined based upon nitrogen content).

0.5 g urea. As attenuation coefficient depicts transparency of a material [34], from the obtained data it can be disclosed that the transparency of milk brand 2 and the imitated milk containing 1 g urea is approximately similar. Same disclosure can be made in case of milk brand 1 and milk sample containing 0.5 g urea. Similarity between the imitated and market samples can indicate the potent use gamma radiation to detect adulterants (Table 6 and 7).

According to the obtained analytical data, Milk brand 1 and 3 showed similar fat content that is 1.5%. Milk brand 2 possessed 0.5% fat. Protein content was found higher in milk brand-1 (3.4%). The lowest protein was obtained in milk brand-3 (3.2%) (Figs. 7, 8 and 9).

Upon 24 h of exposure to gamma source, the commercial milk samples were stored maintaining the same condition that is at room temperature (22 °C) and the lids of the container were left open. Milk brand 2 showed zero count after 48 h. Rest samples showed zero count after 72 h. Irradiated commercial milk samples did not show any sour smell or spoilage until fourth day, although the samples showed zero count after 72 h. Samples with radiation exhibited mild foul smell and showed lesser precipitation after boiling on fifth day of storage. Milk brand 2 showed smallest grainy particles of coagulated proteins among other two samples. Milk brand 3 showed the largest coagulated lumps. Non-irradiated all the commercial milk samples exhibit sour smell on

Table 4

Fat and protein percentages of adulterated milk samples.

SAMPLES	Fat (%)	Protein (%)
sample + Vegetable oil + 0.5 gm urea	4.38 ± 0.02 ^b	3.88 ± 0.16 ^c
sample + Vegetable oil +1 gm urea	4.45 ± 0.09 ^a	3.9 ± 0.08 ^b
sample+ 0.5 gm urea	4.19 ± 0.25 ^d	3.88 ± 0.33 ^{ab}
sample+1 g urea	4.25 ± 0.19 ^c	3.91 ± 0.02 ^a
sample + gluten	3.83 ± 0.11 ^e	3.23 ± 0.01 ^d
sample	3.81 ± 0.01 ^{de}	3.19 ± 0.05 ^e

Note: Data presented are nutrient compositions of the milk samples. significantly different, $p < 0.05$ (Statistical analysis has been done row wise).

Table 5

Attenuation coefficient of market milk samples.

	Nb (Background radiation count)	Nc (Radiation count)	Height of milk samples (cm)	Density	Linear attenuation	Mass attenuation
Milk brand 1	33	109 ± 1.51 ^b	2.5	0.8	0.313 ± 0.08 ^b	0.391 ± 0.18 ^b
Milk brand 2		121 ± 0.29 ^a		0.833	0.277 ± 0.12 ^c	0.332 ± 0.04 ^c
Milk brand 3		105 ± 0.14 ^c		0.851064	0.351 ± 0.01 ^a	0.413 ± 0.90 ^a

Note: Data presented are radiation counts in the exposed market milk samples. significantly different, $p < 0.05$ (Statistical analysis has been done row wise).

fourth day indicating initiation of protein coagulation due to low pH. For more proper visualization of protein coagulation, samples were heated and visible grainy particles of coagulated milk protein were observed. After exhibition of sour smell upon boiling of the commercial milks, irradiated samples and non-irradiated samples showed the same pattern of visible coagulated proteins. Irradiated samples showed smaller granular texture of coagulated proteins than the coagulated lumps obtained from non-irradiated milk samples.

Besides the study of nutrients available and effect of gamma radiation on milk samples, fat separation pattern of the imitated sample during storage was also observed. Fat separation of milk samples showed inversely proportional relation with concentration of added adulterants in the sample. Pure milk showed more fat separation in comparison with imitated milk and commercial milk samples. Milk sample containing urea, vegetable oil and water showed lesser or no fat separation. Market milk samples showed negligible fat separation. According to previous studies in case of market milk, natural fat present in milk is extracted and replace them with vegetable oil to compensate profit [1].

Estimated data obtained from the comparative study of the interaction between gamma radiation and different milk samples viz., pure (unadulterated) milk, imitated (adulterated) milk, commercial milk, disclosed that gamma radiation can be utilized as potent detector of adulterants present in milk sample in cost-effective way. By studying the pattern of attenuation coefficient of different milk samples, added elements in sample can be predicted. Size of obtained curdled lumps of coagulated milk proteins also depicts the degree of concentration of added adulterants in milk samples in inversely proportional manner. According to the obtained data, granular the texture of coagulated proteins, higher concentration of adulterants might be present in the milk. Moreover, the nature of the texture of the curdled coagulated proteins obtained from the milk samples can depict the binding property the obtained curdled mass which are used to formulate dairy products like paneer. The curdled mass is obtained due to excess growth of lactobacillus in milk and generation of lactic acid in milk resulting in low pH (acidic media). Due to low pH, milk protein starts to coagulate. Upon

boiling, in the presence of heat and acidic environment, the protein gets oversaturate and results in visual grainy or lumpy texture of coagulated milk proteins. Imitation of the same environment is carried out using citric acid or lemon juice in paneer preparation. Generation of low pH and heating results in curdled mass from which paneer is made. In case of smaller size of granular curdled particles/crystals (coagulated milk proteins) observed in market milk sample, blending of the obtained mass gave smooth and consistent structure leading to proper shaped paneer. This paneer did not break easily upon cooking and gave rubber like texture. Previous study on other macronutrient like starch showed enhanced binding property on increased granulation [37]. Alternatively, large sized lumps of curdled mass obtained from fresh milk did not give smooth blend. Paneer prepared from unadulterated fresh milk, easily de-structured on cooking which is an appropriate characteristic to differentiate composition of milk based on purity.

4. Conclusions

Milk samples are adulterated for commercial purpose and economical profit as these milk samples possess longer shelf life. Due to expensive and time consuming methods, milk adulteration detection sometimes become challenging. Therefore, the present study disclosed the determination of radiation attenuation property of milk using gamma sources indicating rapid detection of adulterants. Lower attenuation property was observed in case of adulterated milk samples (0.188 ± 0.32 for milk sample containing vegetable oil and urea), whereas the fresh unadulterated milk (0.379 ± 0.04) attenuated the higher amount of radiation due its high viscosity. The linear attenuation of the market samples was recorded in the range of 0.277–0.351, which is lower than the attenuation of the fresh milk sample. Present study also demonstrated that during the analysis of coagulated milk protein structure, obtained from curdled milk samples, adulterated samples showed granular particles and fresh one showed larger curdled mass. Dairy products like *paneer* made from adulterated milk, exerts firm structure due to the granular particles. The observed structural changes in the coagulated milk protein obtained from the fresh unadulterated as well as

Table 6

Fat and protein present in market milk samples.

Place	Samples	Total Fat (%)	Protein (%)
Churu dairy	Milk brand 1	1.5 ± 0.02 ^a	3.4 ± 0.11 ^a
Gurugram	Milk brand 2	0.5 ± 0.30 ^b	3.3 ± 1.05 ^b
Rajasthan	Milk brand 3	1.5 ± 0.01 ^{ab}	3.2 ± 0.99 ^c

Note: Data presented are nutrient compositions of the milk samples. significantly different, $p < 0.05$ (Statistical analysis has been done row wise).

Table 7

Obtained counts in market milk samples.

	24 h	48 h	72 h
Milk brand 1	3 ± 0.02 ^b	1 ± 0.09 ^b	0
Milk brand 2	1 ± 0.11 ^c	0	0
Milk brand 3	5 ± 0.01 ^a	2 ± 1.05 ^a	0

Note: Data presented are radiation counts in the exposed market milk samples. significantly different, $p < 0.05$ (Statistical analysis has been done row wise).

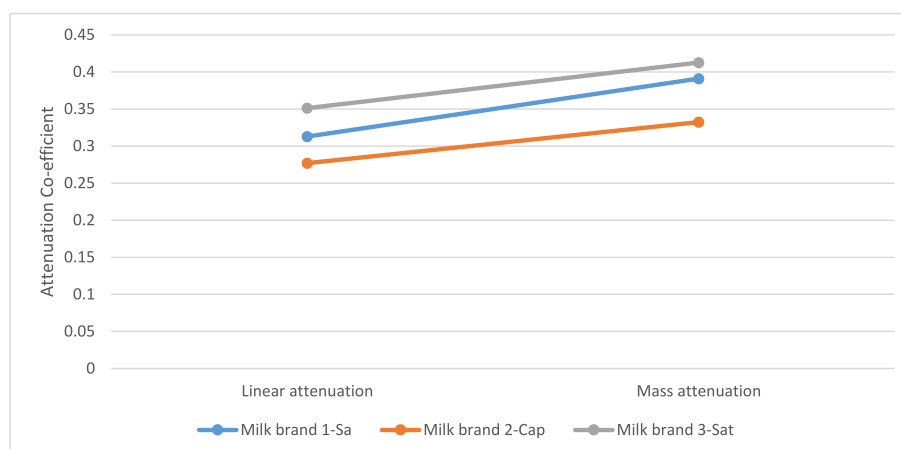


Fig. 7. Graphical representation of attenuation coefficient of market milk samples.

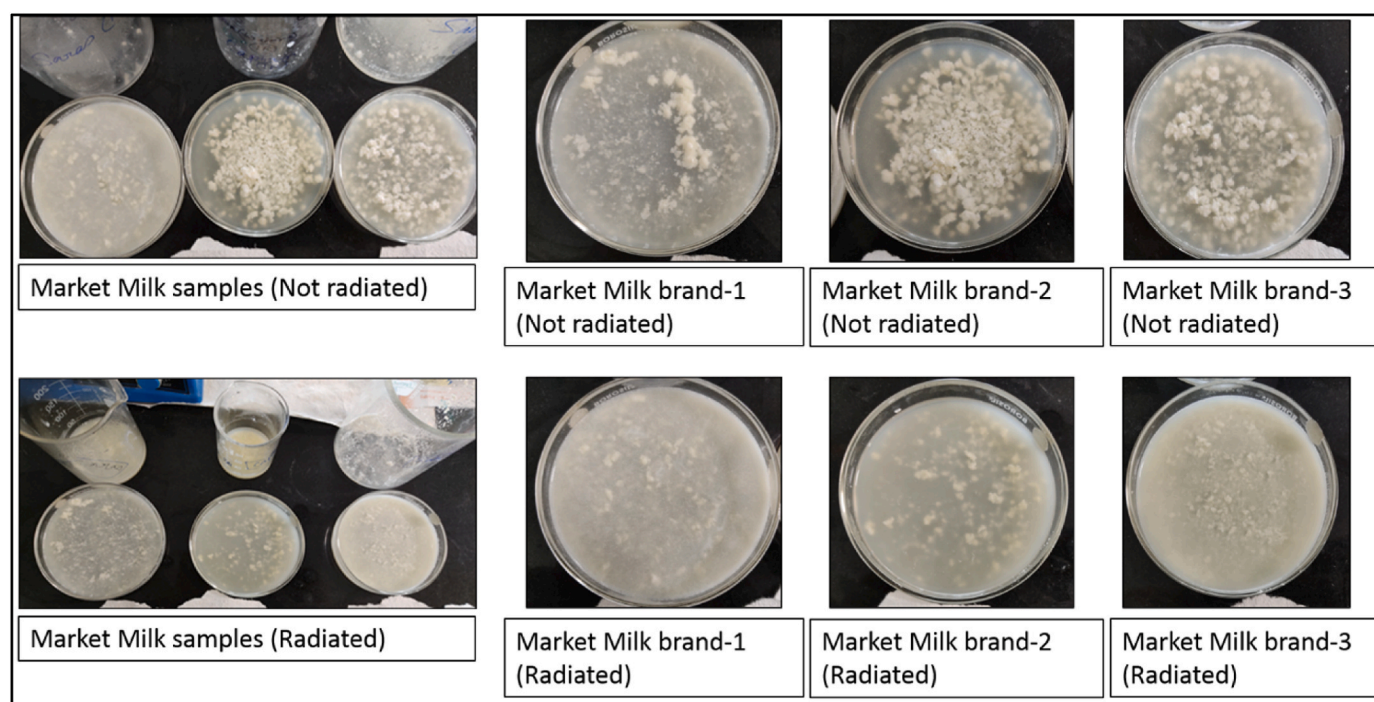


Fig. 8. Curdled mass obtained from market milk samples (Effects of heat treatment and gamma radiation on milk protein coagulation pattern were observed in case of market milk samples).

the commercial and adulterated milk samples in the present study indicated the reason behind the increased malpractice of synthetic milk production. The obtained correlation between attenuation property and different milk protein coagulation patterns in the present study indicated use of cost effective gamma radiation based rapid detection method for adulterants in milk, beneficial to the society.

Funding statement

This research did not receive any specific grant from funding agencies for publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

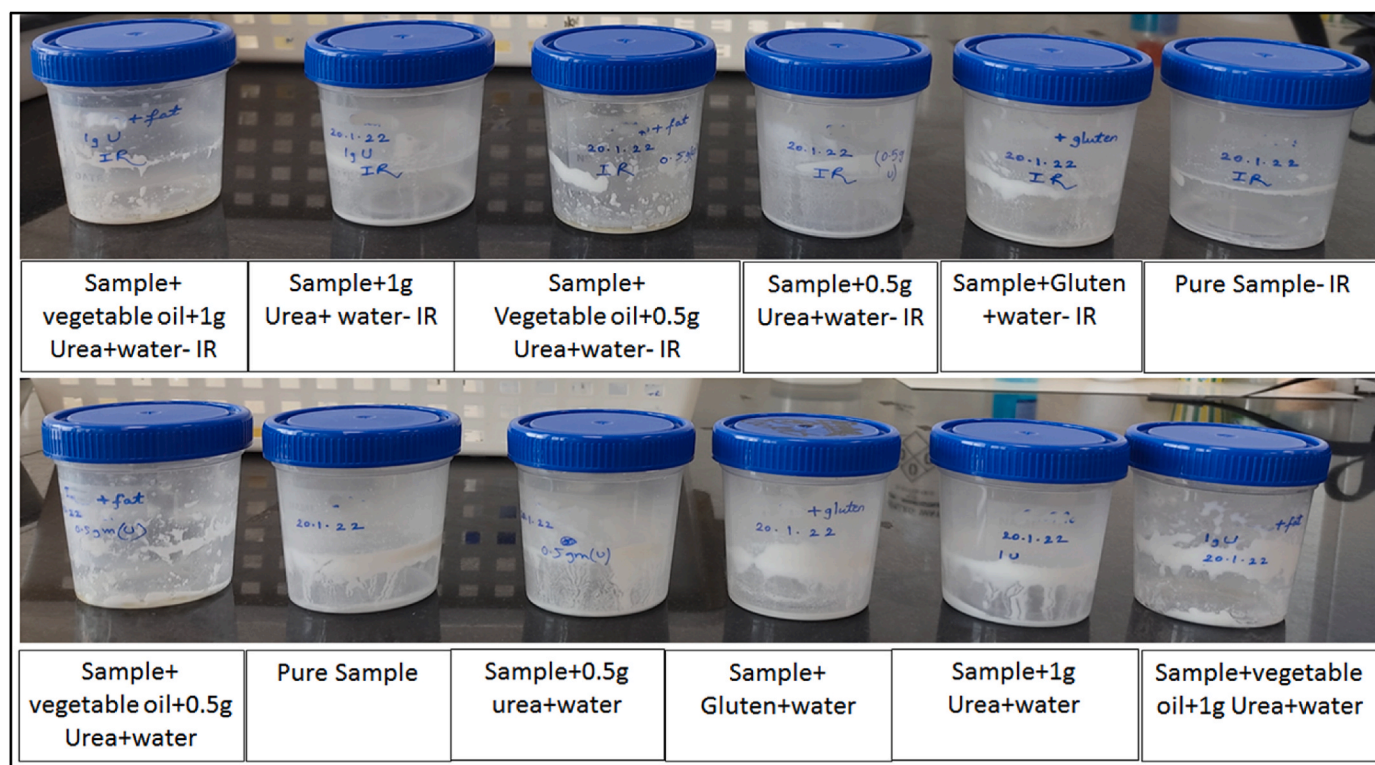


Fig. 9. Fat separation of imitated milk samples (irradiated and non-radiated).

Acknowledgement

We acknowledge Central University of Haryana for providing required facilities for this study.

References

- [1] D. Mudgil, S. Barak, Synthetic milk: a threat to Indian dairy industry, *Carpathian J Food Sci Technol* 5 (1–2) (2013) 64–68.
- [2] P. Bansal, N. Bansal, Synthetic milk: genesis, current status and options, *Curr. Sci.* 73 (11) (1997) 904–905.
- [3] R. Sharma, Y.S. Rajput, S. Kaur, S.K. Tomar, A method for estimation of urea using ammonia electrode and its applicability to milk samples, *J. Dairy Res.* 75 (4) (2008) 466–470.
- [4] WHO (World Health Organization), Background paper on methods for the analysis of melamine and related compounds in foods and animal feeds, Available from, <http://www.who.int/topics/melamine/en>, 2009. (Accessed 12 May 2011).
- [5] WHO (World Health Organization), Toxicological and health aspects of melamine and cyanuric acid, Available from, <http://www.who.int/topics/melamine/en>, 2009. (Accessed 12 May 2011).
- [6] US FDA, Joint update: FDA/USDA trace adulterated animal feed to poultry, Available from, www.fda.gov/bbs/topics/NEWS/2007/NEW01621.html. (Accessed 10 July 2007).
- [7] M.A. Karlsson, Å. Lundh, F. Innings, A. Höjer, M. Wikström, M. Langton, The effect of calcium, citrate, and urea on the stability of ultra-high temperature treated milk: a full factorial designed study, *Foods* 8 (9) (2019) 418.
- [8] R.P.W. Williams, The relationship between the composition of milk and the properties of bulk milk products, *Aust. J. Dairy Technol.* 57 (1) (2002) 30.
- [9] S.V. Crowley, M. Megemont, I. Gazi, A.L. Kelly, T. Huppertz, J.A. O'Mahony, Heat stability of reconstituted milk protein concentrate powders, *Int. Dairy J.* 37 (2) (2014) 104–110.
- [10] M. Kartheek, A.A. Smith, A.K. Muthu, R. Manavalan, Determination of adulterants in food: a review, *J. Chem. Pharmaceut. Res.* 3 (2) (2011) 629–636.
- [11] S. Gahlawat, S. Kumari, N. Boora, Y.V.R.K. Sharma, Screening of adulterants in the milk and dairy products of Delhi region—a case study, *Int. J. Pharm. Technol.* 4 (4) (2012) 4889–4897.
- [12] M. Ayub, Q. Ahmad, M. Abbas, I.M. Qazi, I.A. Khattak, I.A. Khattak, Composition and adulteration analysis of milk samples, *Sarhad J. Agric.* 23 (4) (2007) 1127.
- [13] S. Nirwal, R. Pant, N. Rai, Analysis of milk quality, adulteration and mastitis in milk samples collected from different regions of Dehradun, *International Journal of PharmTech Research* 5 (2) (2013) 359–364.
- [14] A.A. Soomro, M. Khaskheli, M.A. Memon, G.S. Barham, I.U. Haq, S.N. Fazlani, R. N. Soomro, Study on adulteration and composition of milk sold at Badin, *Intl J Res Appl Nat Social Sci* 2 (9) (2014) 57–70.
- [15] A. Afzal, M.S. Mahmood, I. Hussain, M. Akhtar, Adulteration and microbiological quality of milk (a review), *Pakistan J. Nutr.* 10 (12) (2011) 1195–1202.
- [16] G. Monika, M.P. Gupta, Recent Trends in Detection of Adulteration of Milk and Dairy Products, *diary Book*, Varanasi, 2008.
- [17] L.M. Chaudhari, S.B. Girase, Determination of adulteration in milk samples by attenuation coefficient using nuclear technique, *Arch. Appl. Sci. Res.* 5 (2) (2013) 255–260.
- [18] Risk assessment studies report No. 15, Chemical Hazard Evaluation, Risk Assessment on Artificial Sweeteners in Beverages, Food and Environmental Hygiene Department, HKSAR, Risk Assessment Section, Food and Environmental Hygiene Department 43/F, Queensway Government Offices, 66 Queensway, Hong Kong, November 2003.
- [19] J. Spink, Safety of Food and Beverages: Risks of Food Adulteration, 2014.
- [20] L.A. Ferrari, L. Giannuzzi, Clinical parameters, postmortem analysis and estimation of lethal dose in victims of a massive intoxication with diethylene glycol, *Forensic Sci. Int.* 153 (1) (2005) 45–51.
- [21] B. Mégarbane, S.W. Borron, F.J. Baud, Current recommendations for treatment of severe toxic alcohol poisonings, *Intensive Care Med.* 31 (2) (2005) 189–195.
- [22] L.J. Schep, R.J. Slaughter, W.A. Temple, D.M.G. Beasley, Diethylene glycol poisoning, *Clin. Toxicol.* 47 (6) (2009) 525–535.
- [23] J.H. Hubbel, S.M. Seltzer, Tables of X-ray mass attenuation coefficients and mass energy-absorption coefficients from 1 keV to 20 MeV for elements Z = 1 to 92 and 48 additional substances of dosimetric interest, *Int. J. Appl. Radiat. Isot.* 33 (1982) 126.
- [24] G.S. Mudahar, S. Modi, S. Makhani, Total and partial mass attenuation coefficients of soil as a function of chemical composition, *Int. J. Radiat. Appl. Instrum. Appl. Radiat. Isot.* 42 (1) (1991) 13–18.
- [25] L. Gerward, On the attenuation of X-rays and γ -rays in dilute solutions, *Radiat. Phys. Chem.* 48 (6) (1996) 697–699.
- [26] L.M. Chaudhari, M.T. Teli, Linear attenuation (or absorption) coefficient of gamma radiation for dilute solutions of potassium chloride, *Appl. Radiat. Isot.* 47 (3) (1996) 365–367.
- [27] M.T. Teli, On the attenuation of X-rays and γ -rays for aqueous solutions of salts, *Radiat. Phys. Chem.* 53 (6) (1998) 593–595.
- [28] L.M. Chaudhari, R. Nathuram, Absorption coefficient of polymers (Polyvinyl Alcohol) by using gamma energy of 0.39 MeV, *Bulg. J. Phys.* 37 (2010) 232–240.
- [29] S.R. Mitkar, S.M. Dongarge, Measurement of linear and mass attenuation coefficient of alcohol soluble compound for gamma rays at energy 0.511 MeV, *Arch. Appl. Sci. Res.* 4 (4) (2012) 1748–1752.
- [30] L.M. Chaudhari, S.Z. Rathod, Measurement of attenuation coefficient of glucose solution, *J. Chem. Biol. Phys. Sci.* 3 (3) (2013) 2087.
- [31] J. Hendrichs, K. Bloem, G. Hoch, J.E. Carpenter, P. Greany, A.S. Robinson, Improving the cost-effectiveness, trade and safety of biological control for agricultural insect pests using nuclear techniques, *Biocontrol Sci. Technol.* 19 (sup1) (2009) 3–22.

- [32] C. Udagani, T.N. Ramesh, Detection and quantitative determination of diethylene glycol in ethyl alcohol using gamma-ray spectroscopy, *J. Food Sci. Technol.* 52 (8) (2015) 5311–5316.
- [33] AOAC, Official Methods of Analysis of AOAC, International seventeenth ed., USA Association of Analytical Communities, Gaithersburg, MD, 2000.
- [34] S. Ghosh, M.K. Das, Attenuation coefficients and absorbed gamma radiation energy of different varieties of potato, mango and prawn at different storage time and physiological condition, *Food Chem.* 145 (2014) 694–700.
- [35] P. Limkitjaroenporn, J. Kaewkhao, W. Chewpraditkul, P. Limsuwan, Mass attenuation coefficient and effective atomic number of Ag/Cu/Zn alloy at different photon energy by Compton scattering technique, *Procedia Eng.* 32 (2012) 847–854.
- [36] T. Huber, K. Starling, W.S. Cen, C. Fee, S. Dimartino, Effect of urea concentration on the viscosity and thermal stability of aqueous NaOH/urea cellulose solutions, *J. of Poly.* 2016 (2016).
- [37] H. Nawaz, R. Waheed, M. Nawaz, D. Shahwar, Physical and chemical modifications in starch structure and reactivity, in: *Chemical Properties of Starch*, IntechOpen, 2020, <https://doi.org/10.5772/intechopen.88870>.