

Electron Beam Irradiation Effects on Variable Starch Content Flat-Type Rice Noodle Physicochemical and Microbial Properties

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Flat rice noodles (FRN) or *kuetiau* made from rice and starch are popular in Malaysia. FRN is a non-gluten noodle and requires gelatinisation of starch during processing. FRN is considered a highly perishable food due to its high moisture content, which is susceptible to microbial deterioration. Electron beam irradiation was performed on FRN's physical, chemical, and microbiological properties. FRN was prepared with 90% rice flour; the remaining 10% was either tapioca, potato, or sago. The noodle was then irradiated at 0, 3, 6, and 9 kGy by electron beam (EB). EB irradiation significantly increased the firmness, breaking length, and cooking loss, whereas the cooking yield and yellowness (b^*) of the FRN were significantly decreased. However, all irradiation doses did not affect the pH, water activity, moisture content, lightness (L^*), and greenness (a^*). The total plate count (TPC) of the FRN was determined on days 0, 2, 4, 6, 8, and 10. The results showed that the irradiation dose at 9 kGy was the most effective as it reduced the microbial count until day 10. Thus, the pH, moisture content, water activity, lightness, and greenness of FRN were not changed by EB irradiation, but the textural and cooking qualities were considerably altered.

Keywords: flat rice noodle; electron beam; firmness; breaking length; microbial quality

I. INTRODUCTION

Noodles are one of the famous dishes in Asia. Many types and varieties of noodles are made from wheat, rice, and buckwheat. Noodles are the second most preferred food after bread in global food consumption and are widely consumed by people (Kulkarni *et al.*, 2012). Flat rice noodle (FRN) is a famous dish around Southeast Asia for their unique texture and shape. Different names also called FRN according to the culture and region, such as *kuetiau* in Malaysia and *pad thai* in Thailand. Noodles are produced from long rice grains with a high amylose content (> 22%) (Juliano, 1985), which is essential in

forming a gel network and contributing to the noodles' textural qualities. The rice noodles are made of mainly rice flour and added with starches, most often tapioca and potato starch. The starches are added to aid the desired gelatinous, chewy, slippery texture and white appearance of the noodles (Fu, 2008). Since rice noodles do not contain any gluten, they have grown popular among those with wheat sensitivities, celiac disease, and other conditions that necessitate avoiding gluten. Prior to extrusion, the rice undergoes several processes. Rice is milled, filtered, pulverised, moulded into balls, pre-cooked, kneaded, and extruded. Sheeted or FRN is made by putting the

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dough on a rotating heated drum, forming a sheet, and cutting it into strips.

Fresh FRN has a very short life due to high moisture content and high nutrient substances which can lead to microbial spoilage and foodborne contamination (Li *et al.*, 2012; Shi *et al.*, 2020). Bacteria, yeast, and moulds are the common microorganisms found to spoil fresh FRN. Consequently, the rice noodles industry faces a problem where FRN can spoil even though being stored in a freezer (Ismail *et al.*, 2016). The hurdling technique achieves a longer shelf life for freshly made noodles and incorporates preservatives, a frequently employed technique by industry. Although there are various methods to achieve this, many people opt for using preservatives like sodium dehydroacetate, calcium propionate, and potassium sorbate, due to their affordability and ease of use without requiring complex methods or technology (Li *et al.*, 2011). However, consumers are more aware and concerned about chemical preservatives and demand a healthier food choice. Although natural preservatives such as chitosan and xylose were attempted in noodles, they can only extend the shelf life for a few days more than the average shelf life (Li *et al.*, 2011). In addition, preservatives may change the flavour of the fresh noodle. Therefore, other options to preserve fresh rice noodles should be explored.

Irradiation is a good alternative to preserve and extend the shelf life of rice noodles. This technique is common to extend shelf life and improve food safety (Lacroix *et al.*, 2004). Irradiation technique is a non-thermal heat processing that could extend the shelf life of food products by killing the bacteria on the food surface with minimal effect on the quality and nutritional value of the food. The three types of irradiations used for food preservation are electron beam (EB), X-rays, and Gamma rays. The irradiation technique involves exposing food to doses of ionising energy or radiation. At lower doses, irradiation can extend the product's shelf life, whereas, at higher doses, exposure kills insects, moulds, bacteria, and harmful microorganisms. Gamma rays are produced by the radioactive substances commonly from Cobalt-60 while X-rays and electron beams are produced from an accelerator (Riganakos, 2010). Gamma-ray is the typical type of radiation

used in food preservation. Previous studies showed that noodles treated with gamma rays at 4 kGy showed the best sensory stability and storage time (Li *et al.*, 2011). Due to high penetration, gamma-ray is preferred for food irradiation as compared to EB and X-rays. However, the price increase of Cobalt-60 and increased public concern about radioactive disposal led to the development of EB and X-ray machines (Rather *et al.*, 2019). Nevertheless, consumers still need to be convinced about using X-rays and EB in the food industry. EB irradiation technique has some advantages over the gamma rays technique as it is instantaneous, absent any radioactive substance, and environmentally friendly (Bhat *et al.*, 2012). It is also considered a non-thermal sterilisation method with a high power utilisation rate and lower operation cost (Wei *et al.*, 2014).

Previous research proved that EB treatment was able to prevent microbial spoilage by the destruction of the DNA protein of the microorganisms. Fresh noodles can now be stored for up to 28 days while maintaining acceptable microbial quality by treating them with 4.0 kGy of EB irradiation, as stated by Shi *et al.* (2020). The shelf-life of dried apricots was also extended by using EB Irradiation at 3 kGy, and the viable microorganisms were below the detection limit (Wei *et al.*, 2014). Although the effectiveness of EB was proven on fresh noodles, it was intended for noodles made from wheat flour (Shi *et al.*, 2020). It is crucial to study the effectiveness of EB on the shelf life of FRN because FRN is made mainly from rice flour and a small portion of other starches. The EB may also affect the physicochemical properties of FRN added with different types of starch due to the different amylose-amylopectin ratio, starch molecular weight, and starch granule sizes and shapes. Hence, we are interested in finding whether FRN with 10% tapioca starch, potato starch, or sago starch exposed to different RB irradiation dosages will affect the physicochemical attributes and microbiological quality. We hypothesised that the shelf life of FRN will be significantly extended with overall improvements in the texture, microbial counts, and cooking yield. This study sets out to quantify the impact of EB radiation dose on the physical, chemical, and

microbiological aspects of FRN with different starch compositions.

II. MATERIALS AND METHODS

A. Raw Materials

The raw materials for the FRN were rice flour, water, tapioca starch, potato starch, sago starch, and oil obtained from a local grocery store in Serdang, Malaysia.

B. Flat Rice Noodles Formulation

Table 1 shows the formulations of flat rice noodles.

Table 1. The formulations of flat rice noodle

Ingredients	10%	10%	10%	Control
	TS	PS	SS	
Rice flour (%)	90	90	90	100
Tapioca starch (%)	10	-	-	-
Potato starch (%)	-	10	-	-
Sago starch (%)	-	-	10	-

C. Preparation of Rice Noodles

All the ingredients were weighed accordingly and mixed before steamed in a pan using a steamer. The mixture was steamed for 7 minutes. After that, the noodles were sheeted and cut into uniform sizes (1/2 inch wide and 1/4 inch thick). The freshly prepared noodles were stored at room temperature in an HDPE plastic bag. The FRN under storage study was analysed for microbial tests to estimate the shelf life.

D. Electron Beam (e-beam) Irradiation

The irradiation treatment was performed by an electron beam machine (EBM) facility at the Malaysian Nuclear Agency. The sample underwent optimisation with 1, 2, and 3 layers of flat rice noodles and was later treated using a single beam exposure (EPS3000) with an accelerated voltage of 1.0 MeV and beam currents of 1 mA. The samples were irradiated in polyethylene

zip lock bags with 3, 6, and 9 kGy doses with 3 kGy intervals checked by cellulose triacetate (CTA) standard dosimetry procedure.

E. Moisture Content

The sample's moisture content was determined through the oven drying method, adhering to the procedure outlined by Zawawi *et al.* (2014). The sample was subjected to a drying process lasting 8 h, at a temperature of 105 °C.

F. Water Activity

According to Park (2008), AquaLab Series 4 TE DUO was used to determine the water activity of the sample.

G. Determination of pH

Determination of the pH of samples was carried out using a pH meter (Model 320, Mettler-Toledo Ltd., Essex, UK) by Ho and Che Dahri (2016) slightly modified technique. Prior to use, the pH meter underwent calibration at pH 7.0 and 4.0.

H. Cooking Properties

The yield and loss during cooking were calculated using a slightly modified method from (Zawawi *et al.*, 2014). The cooking loss of noodles was calculated based on the equation (1) below:

$$\text{Cooking loss (\%)} = \frac{(\text{Weight of the drained residue in the cooking water (g)})}{(\text{Noodle weight before cooking (g)})} \times 100 \quad (1)$$

The equation (2) below was used to calculate precisely the cooking yield:

$$\text{Cooking Yield (\%)} = 100 \times \frac{W_{ch}}{W_{cr}} \quad (2)$$

W_{cr} = The cooked sample's raw weight

W_{ch} = The cooked sample's hot cooked weight

I. Colour Measurement

The colour of the noodle was assessed with a chroma meter (CR-400 Konica Minolta Japan) by referring to Zawawi *et al.* (2014) with a slight modification. The lightness (L^*),

red/greenness (a^* , \pm red-green), and yellow/blueness (b^* , \pm yellow-blue) were determined.

J. Textural Properties

As part of the texture profile analysis, the FRN's hardness was conducted. The instrument for determining hardness is a CT3 Texture Analyzer (TexturePro CT V1.4, United States) with a load cell of 4500 g and a speed of 2.0 mm. The firmness of the noodles is determined using a wide acrylic knife (8 g, 60 mm). Five strands of noodles were placed on the fixture base table, and then the knife was used to cut the noodles at a distance of 20 mm from the probe to the fixture base table. Four replicates were recorded for each sample.

Using the same CT3 Texture Analyzer with various probe types, the breaking length of the FRN was determined. For the breaking length, a dual grip assembly was selected as the probe type. Noodles were gripped at both ends with a 100 mm adjust beam and 12 mm target value. Three replicates were recorded for each sample.

K. Total Plate Count (TPC)

The method of determination of TPC was determined according to (Suwaibah *et al.*, 2009). A stomacher machine (Stomacher 400 Circulatory, Seward Ltd., West Sussex, UK) was used to homogenise the sample (25 g) in 225 mL of 0.1% peptone water in a stomacher bag. To create a series of dilutions, a 0.1% peptone water solution was utilised. Subsequently, 0.1 mL was extracted from each dilution and spread evenly onto plate count agar (PCA) plates. These plates were then placed in an incubator set at 37 °C for a duration of 48 ± 2 h.

L. Statistical Analysis

Using Minitab 18, the data were statistically analysed. Using a Turkey test, a one-way analysis of variance was performed using tests with a significance level of $p < 0.05$. This analysis aimed to detect any significant deviations between the average values. The study outcomes were presented as the mean \pm standard deviation of three independent replicates. In a

multiple-range analysis with a 95% confidence level, different letters in the figures denote significant differences.

III. RESULTS AND DISCUSSION

A. The Irradiation of Flat Rice Noodles with An Electron Beam and Its Effect on Their Physical and Chemical Properties

The moisture content (MC) of 10% TS, 10% PS, 10% SS, and control with varying dosages of irradiation is shown in Figure 1. The results showed that all the MC of the samples decreased with increasing irradiation dose except 10% PS (Liang *et al.*, 2023). Irradiation did not significantly alter the MC ($p > 0.05$) between the samples exposed to varied irradiation doses, suggesting that irradiation had little effect on the samples. A study on irradiated water spinach noodles also showed no significant difference in the MC of the sample when the irradiation dose increased (Nor Afizah *et al.*, 2020). There was no moisture loss during the sample treatment as irradiation is a non-thermal process.

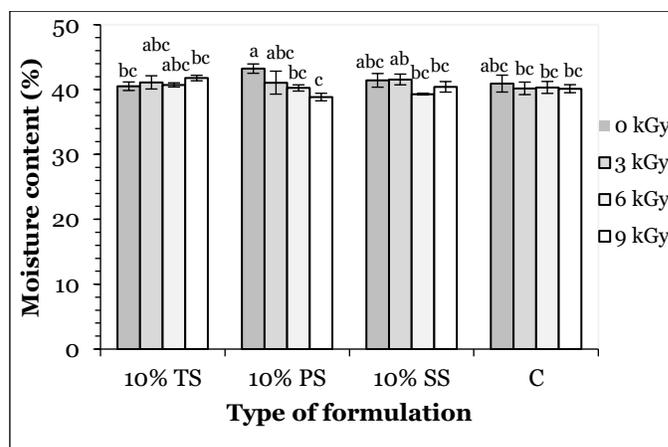


Figure 1. Moisture content of FRN

Similar superscripts within a column denote that there are no statistical differences ($p > 0.05$).

Table 2. The water activity of flat rice noodle

Irradiation Dose (kGy)	10% Tapioca Starch	10% Potato Starch	10% Sago Starch	Control
0	0.919 ± 0.015 ^a	0.927 ± 0.031 ^a	0.958 ± 0.023 ^a	0.948 ± 0.005 ^a
3	0.955 ± 0.015 ^a	0.899 ± 0.048 ^a	0.914 ± 0.023 ^a	0.895 ± 0.003 ^a
6	0.956 ± 0.021 ^a	0.874 ± 0.028 ^a	0.910 ± 0.032 ^a	0.898 ± 0.051 ^a
9	0.929 ± 0.044 ^a	0.887 ± 0.027 ^a	0.911 ± 0.032 ^a	0.894 ± 0.034 ^a

Values are means of three replicates ± SD. Similar superscripts within a column denote that there are no statistical differences ($p > 0.05$).

Table 2 shows the water activity of the FRN with increasing irradiation dose. The results showed no significant difference ($p > 0.05$) among all 16 samples. The water activity of the FRN varied between 0.919 to 0.958. The results obtained were lower than a study on the water activity of rice noodles (0.979) (Ismail *et al.*, 2016). A product with 0.91 water activity or higher is considered highly perishable. The product can be vulnerable to microorganisms such as *Salmonella*, *Staphylococcus aureus*, and spoilage moulds. After being treated with EB irradiation, the water activity of 10% PS and 10% SS decreased. However, no significant difference ($p > 0.05$) in water activity was seen between non-irradiated noodles and those irradiated. The result was similar to wet spinach yellow noodles treated with gamma irradiation, where the water activity had no significant difference with increasing irradiation dose. Water activity is an essential factor in the quality and stability of food products. It is also a determinant factor for the growth of bacteria and spoilage in food (Ismail *et al.*, 2016).

Table 3. The pH value of FRN

Irradiation Dose (kGy)	10% Tapioca Starch	10% Potato Starch	10% Sago Starch	Control
0	6.52 ± 0.04 ^a	6.66 ± 0.03 ^b	6.69 ± 0.04 ^c	6.69 ± 0.03 ^d
3	6.54 ± 0.03 ^{bc}	6.51 ± 0.02 ^{cd}	6.49 ± 0.04 ^{cd}	6.51 ± 0.01 ^{cd}
6	6.47 ± 0.04 ^{cd}	6.51 ± 0.04 ^{cd}	6.47 ± 0.03 ^{cd}	6.47 ± 0.03 ^{cd}
9	6.52 ± 0.02 ^{bed}	6.44 ± 0.03 ^d	6.62 ± 0.03 ^{ab}	6.66 ± 0.04 ^a

Values are means of three replicates ± SD. Similar superscripts within a column denote that there are no statistical differences ($p > 0.05$).

Table 3 shows the pH of FRN with different starches and irradiation doses. The results showed a significant difference ($p < 0.05$) in 10% PS between untreated and treated samples. The pH of the 10% PS was slightly decreased as the irradiation dose increased. The pH lowering of irradiated starch may be due to starch molecule breakdown and the formation of COOH (Sokhey & Chinnaswamy, 1993). A study on irradiated sago starch using EB treatment with 10 kGy, 15 kGy, and 30 kGy showed that the pH reduced and reached the acidic range, which may be caused by the action of free radicals (Pimpa *et al.*, 2007). The radiation dose applied in this investigation was substantially less intense than the one employed in the earlier study, which explained why the pH of the sample was not drastically changed.

B. Textural Properties

Table 4. The hardness of FRN

Irradiation Dose (kGy)	Hardness of sample (N)			
	10% Tapioca Starch	10% Potato Starch	10% Sago Starch	Control
0	3.23 ± 0.31 ^f	5.59 ± 0.32 ^{de}	4.12 ± 1.03 ^{ef}	4.77 ± 1.17 ^{ef}
3	5.97 ± 2.01 ^{cde}	6.87 ± 0.46 ^{abcd}	6.17 ± 0.39 ^{bcde}	8.37 ± 0.35 ^a
6	7.68 ± 0.41 ^{abc}	7.17 ± 0.25 ^{abcd}	6.06 ± 0.50 ^{cde}	8.13 ± 0.70 ^{ab}
9	7.84 ± 0.47 ^{abc}	8.02 ± 1.37 ^{abc}	7.76 ± 1.74 ^{abc}	8.83 ± 0.28 ^a

Values are means of three replicates ± SD. Similar superscripts within a column denote that there are no statistical differences ($p > 0.05$).

The FRN hardness for a variety of starches and irradiation levels is displayed in Table 4. As the irradiation dose was raised, the FRN's hardness rose noticeably. The results contrast with a study where the hardness of dried apricot and quince decreased at doses higher than 2.0 kGy with EB irradiation (Rather *et al.*, 2019). The results also contrast with the previous study, where the hardness of the freshly prepared wet spinach noodles decreased as the irradiation dose increased with gamma radiation (Nor Afizah *et al.*, 2020). Previous studies showed that irradiated sago starch at 10 and 15 kGy increased the gel strength, possibly due to the linear glucans derived from broken amylopectin as an effect of irradiation.

Table 5 shows the breaking length of the FRN with different starch and radiation dose. From the results, the noodles' breaking length was found to increase with irradiation exposure. A significant increase ($p < 0.05$) was found in sample 10% TS and Control between the untreated and treated samples. This result indicates that with an increase in irradiation, the strength and the stretchability of the noodles were increased. Similarly, sago starch's gel strength increased after irradiation with EB at 10 kGy to 15 kGy as a cause of the

linear glucan derived from broken amylopectin due to irradiation (Pimpa *et al.*, 2007).

Table 5. The breaking length of the FRN

Irradiation Dose (kGy)	Breaking length (mm)			
	10% Tapioca Starch	10% Potato Starch	10% Sago Starch	Control
0	0.23 ± 0.37 ^f	0.54 ± 0.05 ^{cde}	0.37 ± 0.08 ^{ef}	0.52 ± 0.08 ^{de}
3	0.57 ± 0.07 ^{cde}	0.50 ± 0.11 ^{de}	0.55 ± 0.09 ^{cde}	0.75 ± 0.10 ^{abc}
6	0.84 ± 0.07 ^{ab}	0.82 ± 0.14 ^{ab}	0.48 ± 0.04 ^{de}	0.66 ± 0.11 ^{bcd}
9	0.89 ± 0.07 ^a	0.80 ± 0.15 ^{ab}	0.80 ± 0.08 ^{ab}	0.73 ± 0.09 ^{abc}

Values are means of three replicates ± SD. Similar superscripts within a column denote that there are no statistical differences ($p > 0.05$).

In wheat noodles, the extensibility and strength of the dough are contributed by gluten proteins consisting of gliadin and glutenin. The higher the protein content, the firmer the noodle's texture will become. However, in rice noodles, the strength came from the non-gluten protein, such as tuberin from potato and tapioca starch. In contrast, a study on irradiated rice showed that the rice's viscosity decreased with an increase in irradiation dose, which may contribute to the softer texture caused by the deformation of starch granules (Wu *et al.*, 2002).

C. Cooking Properties

Figure 2 and Table 6 show the cooking yield and the cooking loss of the FRN, respectively. The results showed that the cooking yield decreased with increased irradiation dose. However, in all formulations, cooking yield did not differ significantly between irradiated and non-irradiated samples. The term "cooking yield" refers to the proportion of cooked noodles to the total weight of noodles before cooking (Zawawi *et al.*, 2014).

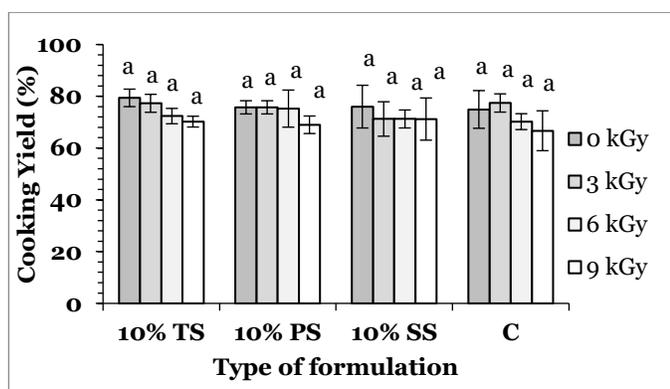


Figure 2. Cooking yield of FRN at different starch

Similar superscripts within a column denote that there are no statistical differences ($p > 0.05$).

Cooking yield indicates the ability of the noodles to absorb water (Chin *et al.*, 2012). Low cooking yield means that the sample had a low ability to absorb and hold the water. The reduction of water-holding capacity was caused by radiation's depolymerisation and shortening of amylose and amylopectin chains (Atrous *et al.*, 2015). Important parameters that impact the cooking qualities of noodles are the cooked weight and cooking loss. Cooking loss is the total solid loss in the water during cooking caused by the starch solubility in the water during boiling (Yalcin & Basman, 2008; Ahmed *et al.*, 2016).

Based on the results in Table 5, 10% PS showed an insignificant increase in the cooking loss percentage with increased irradiation dose. Except for 10% SS, there was no discernible change in samples subjected to higher irradiation doses. The cooking loss of the irradiated sample was significantly higher than that of the non-irradiated sample ($p < 0.05$). Because starch is broken down into simpler components like dextrins, maltose, and glucose during irradiation, the solubility of the starch is increased (Azzeh & Amr, 2009; Dikkala & Shirisha, 2018). High cooking loss is one of the undesirable qualities in noodles as it indicates high solubility of starch, causing the cooking water to become turbid, have low cooking tolerance, and have a sticky mouthfeel (Bhattacharya *et al.*, 1999).

Table 6. Cooking loss of the FRN at different starch

Irradiation Dose (kGy)	10%	10%	10%	Control
	Tapioca starch	Potato Starch	Sago starch	
0	0.06 ± 0.00 ^d	0.05 ± 0.01 ^d	0.52 ± 0.10 ^c	1.21 ± 0.03 ^a
3	0.07 ± 0.02 ^d	0.06 ± 0.01 ^d	0.65 ± 0.06 ^{bc}	1.21 ± 0.09 ^a
6	0.04 ± 0.02 ^d	0.05 ± 0.01 ^d	0.70 ± 0.04 ^{bc}	1.21 ± 0.04 ^a
9	0.04 ± 0.01 ^d	0.07 ± 0.04 ^d	0.65 ± 0.04 ^b	1.19 ± 0.06 ^a

Values are means of three replicates ± SD. Similar superscripts within a column denote that there are no statistical differences ($p > 0.05$).

There exists a significant statistical difference ($p < 0.05$) in the cooking loss amount between the control sample and other formulations. The control had the highest cooking loss compared to the other formulation may be due to the absence of starch. Starch helps noodles to give a better gel texture. Starches from rice flour do not form a firm gel and show a weaker resistance toward shear forces. A low concentration of amylose in noodles leads to higher cooking loss.

D. Colour of Noodle

Table 7 displays the L^* , a^* , and b^* change in colour value of FRN after being exposed to varying doses of EB irradiation. Based on Table 7, 10% TS showed a slight decrease in the lightness (L^*) of FRN. No significant statistical difference ($p > 0.05$) was observed in the L^* and a^* values between the non-irradiated and irradiated samples regardless of irradiation dose. However, the b^* value of untreated and treated samples of 10% TS and PS differed significantly ($p < 0.05$). A study found that the a^* (redness) and b^* (yellowness) values increased as the irradiation dose increased (Pimpa *et al.*, 2007).

Table 7. Colour values of L*, a* and b* of FRN

Irradiation Dose (kGy)	10% Tapioca Starch	10% Potato Starch	10% Sago Starch	Control
L*				
0	73.89±1.65 ^{abc}	74.80±1.46 ^{ab}	74.55±0.97 ^{ab}	74.01±1.09 ^{abc}
3	71.03±2.53 ^{bcd}	76.30±0.78 ^a	71.94±0.90 ^{bcd}	73.18±0.66 ^{abc}
6	70.34±0.64 ^{cd}	73.50±1.28 ^{abc}	73.51±2.15 ^{abc}	74.38±0.28 ^{ab}
9	68.40±1.29 ^d	76.18±1.13 ^a	74.13±0.65 ^{abc}	71.60±0.29 ^{bcd}
a*				
0	-1.54±0.35 ^{bc}	-1.23±0.12 ^{abc}	-0.86±0.01 ^a	-0.88±0.01 ^a
3	-1.10±0.52 ^{abc}	-0.96±0.02 ^{ab}	-1.29±0.02 ^{abc}	-0.94±0.08 ^{ab}
6	-1.22±0.54 ^{abc}	-1.40±0.04 ^{abc}	-1.19±0.07 ^{abc}	-1.02±0.03 ^{ab}
9	-1.71±0.09 ^c	-1.09±0.04 ^{abc}	-1.12±0.03 ^{abc}	-1.28±0.00 ^{abc}
b*				
0	9.19±0.05 ^a	7.22±0.08 ^{ef}	7.48±0.14 ^{cdef}	8.37±0.05 ^{ab}
3	8.23±0.49 ^{bcd}	6.09±0.06 ^g	8.08±0.21 ^{bcd}	8.03±0.19 ^{bcd}
6	8.31±0.24 ^{bc}	7.45±0.21 ^{def}	7.67±0.21 ^{bcd}	7.20±0.42 ^{ef}
9	7.17±0.70 ^f	6.29±0.27 ^g	7.52±0.11 ^{bcd}	6.91±0.15 ^{fg}

Similar superscripts within a column denote that there are no statistical differences ($p > 0.05$).

The caramelisation could cause this result due to starch degradation, which turns the polysaccharides into smaller compounds (Greenwood & Mackenzie, 1963). Colour is one of the quality parameters to determine noodles' quality. Noodle with white and light in colour is desirable for consumers. A study reported that high-quality noodles attain a consistent, long white translucent colour (Fu, 2008).

E. Microbiological Changes

Table 8 shows the TPC of FRN for 10 days after being treated with EB irradiation. The results showed that the treated samples were able to have minimum microbial count up to the 8th day. Samples treated at 9 kGy showed the most effective disinfection results as it has the lowest microbial count. Meanwhile, the untreated samples showed an increase in microbial growth throughout the 10 days. A TPC of 10^6 CFU/g in food can be interpreted as the maximum limit of microbial growth as it is considered spoiled (Suwaibah *et al.*, 2009). The sample of 10% TS without irradiation reached 10^5 CFU/g and is expected to reach 10^6 CFU/g after a few more days.

Table 8. Total plate count of the flat rice noodles

Sample	Total Number of Colonies (log CFU/g)						
	Day 0	Day 2	Day 4	Day 6	Day 8	Day 10	
	0 kGy	3.85 ± 0.06	3.99 ± 0.09	4.21 ± 0.08	4.13 ± 0.15	4.53 ± 0.07	5.02 ± 0.13
10%	3 kGy	<1	<1	<1	<1	<1	<1
TS	6 kGy	<1	<1	<1	<1	<1	<1
	9 kGy	<1	<1	<1	<1	<1	<1
	0 kGy	4.40 ± 0.00	4.42 ± 0.30	spr	spr	5.89 ± 0.23	6.06 ± 0.06
10%	3 kGy	<1	<1	<1	<1	<1	4.23 ± 0.06
PS	6 kGy	<1	<1	<1	<1	<1	<1
	9 kGy	<1	<1	<1	<1	<1	<1
	0 kGy	4.41 ± 0.32	4.65 ± 0.10	spr	spr	5.27 ± 0.26	6.37 ± 0.00
10%	3 kGy	<1	<1	<1	<1	<1	3.70 ± 0.07
SS	6 kGy	<1	<1	<1	<1	<1	4.41 ± 0.00
	9 kGy	<1	<1	<1	<1	<1	<1
	0 kGy	<1	<1	spr	spr	3.75 ± 0.00	4.67 ± 0.20
C	3 kGy	<1	<1	<1	<1	<1	4.66 ± 0.15
	6 kGy	<1	<1	<1	<1	<1	4.66 ± 0.09
	9 kGy	<1	<1	<1	<1	<1	<1

Values are means of three replicates ± SD. spr: spore; C: Control.

The untreated sample of 10% PS and SS were already considered spoiled as it exceeded the acceptable limit. Although the TPC of some of the FRN increased along the storage, it showed slow microorganism growth. A study showed that using EB treatment with a dosage of 4.0 kGy to 5.0 kGy was able to keep the fresh noodles at an acceptable level for 28 days of storage in room temperature (Shi *et al.*, 2019). The effective dose used in that study was 5 kGy which is lower than this study which is 9 kGy. It may be due to the higher power used. Thus, samples treated at higher dose levels showed a lower log CFU/g.

IV. CONCLUSION

In conclusion, EB irradiation affected the physiochemical properties of the FRN. The moisture content and water activity of the samples showed no discernible changes. In contrast, the pH of the irradiation FRN was noticeably changed. Moreover, an increase in the irradiation dose caused an increase in breaking length, hardness, cooking yield and cooking loss of the FRN. In terms of colour, the b^* value showed a significant difference in 10% TS and 10% PS. Besides, irradiation of EB at 9 kGy showed an effective reduction of microbial load that will extend the shelf life of FRN. The study showed a promising potential of EB irradiation on fresh noodles that maybe applicable to other rice-based noodles.

V. CONFLICT OF INTEREST

The authors declare that there is not any conflicts interest in relation to the work described.

VI. REFERENCES

- Ahmed, I, Qazi, IM, Li, Z & Ullah, J 2016, 'Rice Noodles: Materials, Processing and Quality Evaluation', in *Rice Noodles: Materials, Processing and Quality Evaluation: Proceedings of the Pakistan Academy of Sciences: B. Life and Environmental Sciences*, vol. 53, no. 3, pp. 215-238, Pakistan Academy of Sciences, Pakistan.
- Atrous, H, Benbettaieb, N, Hosni, F, Danthine, S, Blecker, C, Attia, H, & Ghorbel, D 2015, 'Effect of γ -radiation on free radicals formation, structural changes and functional properties of wheat starch', *International Journal of Biological Macromolecules*, vol. 80, pp. 64-76.
- Azzeh, F, & Amr, A 2009, 'Effect of gamma irradiation on physical characteristics of Jordanian durum wheat and quality of semolina and lasagna products', *Radiation Physics and Chemistry*, vol. 78, no. 9, pp. 818-822.
- Bhat, R, Karim Alias, A, & Paliyath, G 2012, 'Use of electron beams in food preservation', eds R Bhat, AA Karim, & G Palivath, in *Progress in Food Preservation*, Wiley Blackwell Publishers, West Sussex, UK, pp. 343-366.
- Bhattacharya, M, Zee, S, & Corke, H 1999, 'Physicochemical properties related to quality of rice noodles', *Cereal Chemistry*, vol. 76, no. 6, pp. 861-867.
- Chin, C, Huda, N, & Yang, T 2012, 'Incorporation of surimi powder in wet yellow noodles and its effects on the physicochemical and sensory properties', *International Food Research Journal*, vol. 19, no. 2, pp. 701-707.
- Dikkala, PK, & Shirisha, S 2018, 'Irradiation of starch and its effect on pasting properties: a review', *International Journal of Current Microbiology and Applied Science*, vol. 7, no. 2, pp. 1618-1625.
- Fu, BX 2008, 'Asian noodles: History, classification, raw materials, and processing', *Food Research International*, vol. 41, no. 9, pp. 888-902.
- Greenwood, C, & Mackenzie, S 1963, 'The irradiation of starch. Part I. The properties of potato starch and its components after irradiation with high-energy electrons', *Starch-Stärke*, vol. 15, no. 12, pp. 444-448.
- Ho, LH, & Che Dahri, N 2016, 'Effect of watermelon rind powder on physicochemical, textural, and sensory properties of wet yellow noodles', *CyTA-Journal of Food*, vol. 14, no. 3, pp. 465-472.
- Ismail, M, Law, C, & Hii, C 2016, 'Transparency phenomena of flat-rice noodles (kuew teow) at drying at soaking variation', *International Food Research Journal*, vol. 23, no. Suppl, pp. S195-S202.
- Juliano, B 1985, 'Miscellaneous rice products', in *Rice: Chemistry and technology*, Am. Assoc. Cereal Chemists, St. Paul, MN, pp. 569-618.
- Kulkarni, S, Desai, A, Ranveer, R, & Sahoo, A 2012, 'Development of nutrient rich noodles by supplementation with malted ragi flour', *International Food Research Journal*, vol. 19, no. 1, p. 309.
- Lacroix, M, Ouattara, B, Saucier, L, Giroux, M, & Smoragiewicz, W 2004, 'Effect of gamma irradiation in presence of ascorbic acid on microbial composition and TBARS concentration of ground beef coated with an edible active coating', *Radiation Physics and Chemistry*, vol. 71, no. 1-2, pp. 73-77.
- Li, M, Zhu, KX, Wang, BW, Guo, XN, Peng, W, & Zhou, HM 2012, 'Evaluation the quality characteristics of wheat flour and shelf-life of fresh noodles as affected by ozone treatment', *Food Chemistry*, vol. 135, no. 4, pp. 2163-2169.
- Li, M, Zhu, K, Guo, X, Peng, W, & Zhou, H 2011, 'Effect of water activity (a_w) and irradiation on the shelf-life of fresh noodles', *Innovative Food Science & Emerging Technologies*, vol. 12, no. 4, pp. 526-530.
- Liang, W, Zhao, W, Liu, X, Zheng, J, Sun, Z, Ge, X, Shen, H, Ospankulova, G, Muratkhan, M, & Li, W 2023, 'Investigating the role and mechanism of water in E-beam modified sweet potato starch: Multi-scale structure, physicochemical

- properties, and in vitro digestibility', *Food Hydrocolloids*, vol. 137, p. 108433.
- Nor Afizah, M, Ismail-Fitry, MR, Radhiah, S & Nur Hanani, ZA 2020, 'Effect of gamma irradiation on physicochemical properties and microbiological quality of wet yellow noodle fortified with water spinach (*Ipomoea aquatica*)', *Food Research*, vol. 4, no. 1, pp. 34-41.
- Park, YW 2008, 'Moisture and water activity', eds LML Nollet & F Toldra, in *Handbook of processed meats and poultry analysis*, CRC Press, Taylor & Francis Group, Boca Raton, FL, pp. 35-67.
- Pimpa, B, Muhammad, SKS, Hassan, MA, Ghazali, Z, Hashim, K, & Kanjanasopa, D 2007, 'Effect of electron beam irradiation on physicochemical properties of sago starch', *Songklanakarin Journal of Science and Technology*, vol. 29, no. 3, pp. 759-768.
- Rather, SA, Hussain, PR, Suradkar, PP, Ayob, O, Sanyal, B, Tillu, A, Chaudhary, N, Chavan, RB, & Ghosh, SK 2019, 'Comparison of gamma and electron beam irradiation for using phyto-sanitary treatment and improving physico-chemical quality of dried apricot and quince', *Journal of Radiation Research and Applied Sciences*, vol. 12, no.1, pp. 245-259.
- Riganakos, KA 2010, 'Food irradiation techniques'. IS Arvanitonnis, in *Irradiation of food commodities Techniques, Application, Detection, Legislation, Safety and Consumer Opinion*, Elsevier Inc, New York, pp. 23-42.
- Shi, F, Zhao, H, Song, H, Guo, W, Wang, L, Cui, X, Zhang, W, & Li, S 2020, 'Effects of electron-beam irradiation on inoculated *Listeria innocua*, microbiological and physicochemical quality of fresh noodles during refrigerated storage', *Food Science & Nutrition*, vol. 8, no. 1, pp. 114-123.
- Sokhey, A, & Chinnaswamy, R 1993, 'Chemical and molecular properties of irradiated starch extrudates', *Cereal Chemistry*, vol. 70, no. 3, pp. 260-268.
- Suwaibah, G, Abdulamir, AS, Fatimah, AB, Roselina, K, & Nazamid, S 2009, 'Microbial growth, sensory characteristic and pH as potential spoilage indicators of Chinese yellow wet noodles from commercial processing plants', *American Journal of Applied Sciences*, vol. 6, no. 6, pp. 1059-1066.
- Wei, M, Zhou, L, Song, H, Yi, J, Wu, B, Li, Y, Zhang, L, Che, F, Wang, Z, Gao, M, & Li, S 2014, 'Electron beam irradiation of sun-dried apricots for quality maintenance', *Radiation Physics and Chemistry*, vol. 97, pp. 126-133.
- Wu, D, Shu, Q, Wang, Z, & Xia, Y 2002, 'Effect of gamma irradiation on starch viscosity and physicochemical properties of different rice', *Radiation Physics and Chemistry*, vol. 65, no. 1, pp. 79-86.
- Yalcin, S, & Basman, A 2008, 'Effects of gelatinisation level, gum and transglutaminase on the quality characteristics of rice noodle', *International Journal of Food Science & Technology*, vol. 43, no. 9, pp. 1637-1644.
- Zawawi, N, Gangadharan, P, Zaini, RA, Samsudin, M, Karim, R, & Maznah, I 2014, 'Nutritional values and cooking quality of defatted Kenaf seeds yellow (DKSY) noodles', *International Food Research Journal*, vol. 21, no. 2, pp. 603-608.