Research Article

Textural and Chemical Changes in Chicken Meat Treated with Irradiation and Coriander Powder

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Abstract | This research investigates the chemical properties and texture of chicken meat influenced by coriander powder supplementation and gamma radiation exposure. The key variables include the addition of coriander powder (CP) at 0% and 3% dry matter (DM) levels and gamma radiation doses of 0, 1, and 2 kGy, with observations conducted on days 0, 7, and 14 of storage. A completely randomized factorial design was employed. Visual assessments revealed that CP treatment resulted in darker meat coloration on the 7th and 14th days of storage. Scanning electron microscope (SEM) analysis indicated that the meat irradiated (1 kGy and 2 kGy) with CP displayed a smoother surface. CP supplementation significantly reduced firmness ($p < 0.01$), and both gumminess and chewiness decreased markedly following irradiation ($p < 0.01$). The inclusion of CP significantly lowered the lightness (L^*) parameter ($p < 0.01$) while enhancing the redness (a^*) and yellowness (b^*) values ($p < 0.01$). Gamma irradiation, however, did not influence color parameters, and apart from protein content, it did not affect the nutritional composition of the chicken meat. In conclusion, the combination of coriander powder and gamma irradiation enhanced the meat's tenderness and chewiness. Additionally, CP helped preserve the meat's color post-irradiation. While gamma irradiation did not alter the overall nutrient composition, it increased Ca content following CP addition.

Keywords | Chicken meat, Corriander powder, Gamma irradiation, Texture

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INTRODUCTION

In 2024, the per capita weekly consumption of chicken meat in Indonesia is projected to reach 0.15 kilograms, reflecting an 18.48% increase from 2020 (Statistics Indonesia, 2024a). This surge in consumption aligns with a concurrent increase in chicken production. According to Statistics Indonesia (Statistics Indonesia, 2024b), the production of broiler chickens in Indonesia reached 3,997,652 tons in 2023, representing a 25.49% rise compared to 2021. Notably, Indonesia has expanded its chicken meat exports to neighbouring countries, including Singapore, Timor

Leste, Thailand, and Australia (Ministry of Agriculture, 2023). Indonesia demonstrates the potential for increased export volumes with the observed production surplus. It is crucial to implement proper handling procedures to preserve the quality and extend the shelf life of chicken meat during export. Additional measures are necessary to ensure the meat remains durable without compromising its nutritional value. Employing chemical, physical, or a combination of both methods can help maintain product hygiene and guarantee consumer food safety (Dinçer and Baysal, 2004). Non-thermal methods are favored for food preservation due to their ability to reduce nutrient loss significantly. Various non-thermal techniques include ultrasonication, cold plasma, supercritical fluids, pulsed electric fields, high hydrostatic pressure, pulsed ultraviolet technology, ozone treatment, and irradiation (Jadhav *et al*., 2021). Irradiation techniques are among the most effective methods used in non-thermal food preservation. This process involves the use of high-energy gamma rays, X-rays, and accelerated electrons, which are the three types of ionising radiation that can be applied to irradiate food (Khalid *et al*., 2023).

Gamma irradiation is a highly efficient method for meat preservation, given that the necessary instrument infrastructure is in place. This technique effectively disrupts biological processes, thereby enhancing the safety and microbiological stability of food (Xavier *et al*., 2018). Doses of 2 and 4 kGy of irradiation can be identified as optimal for maintaining the stability of the physicochemical and sensory characteristics of meat products (Ferdousi *et al*., 2022). A dose of 2 kGy of gamma irradiation significantly reduced the total number of aerobic bacteria and effectively eliminated coliform bacteria in chicken samples over time intervals of 0, 5, and 10 days (Sadiq *et al*., 2023). Several meta-analysis studies and reviews indicate that gamma irradiation leads to increased TBARS and peroxide values (Dimov, 2022; Khalid *et al*., 2023; Wahyono *et al*., 2024; Asmarani *et al*., 2024) . To mitigate these adverse effects, the use of natural antioxidants is recommended (Dimov, 2022; Khalid *et al*., 2023). According to the findings of Indiarto *et al*. (2023), gamma irradiation results in modifications to the color, texture, and water-holding capacity (WHC) of meat. The color properties post gamma irradiation showed a darker appearance, characterised by a decrease in L* values, but an increase in a* and b* values." potentially influencing consumer acceptance (Dimov and Popova, 2022). In addition to reducing lipid oxidation, this herbal plant is also utilised for its antibacterial properties and to minimize residual effects (Arshad *et al*., 2019). The application of herbal ingredients and plant extracts has been extensively employed to mitigate oxidation in meat following gamma irradiation. Notable examples include turmeric powder (Arshad *et al*., 2019), mugwort extracts (Hwang *et al*., 2015), kale leaf powder (Khalid *et al*., 2021), moringa leaf powder (Nisar *et al*., 2019), and ethanol extract from papaya leaves (Abdeldaiem, 2014). The combination of guava leaf extract and gamma irradiation effectively preserves the color stability and sensory attributes of chicken patties during storage (Sadiq *et al*., 2023). Numerous studies have demonstrated that active ingredients can enhance the oxidative stability of meat.

However, when selecting these ingredients, it is crucial to account for their sustainable availability. Coriander (*Coriandrum sativum*) is commonly used as a cooking spice in Indonesia. According to Spence (2023), coriander is gaining popularity as a culinary herb in western countries. This trend may be attributed to the growing popularity and acceptance of Southeast Asian ethnic cuisine, which frequently incorporates this fresh herb. Coriander powder is chosen due to its plentiful availability in tropical regions and its oxidation-preventing active compounds. Coriander plants are renowned for their rich polyphenol content and abundant essential oils. These properties make them frequently utilised as antioxidants, antibacterial, and anti-inflammatory agents (Scandar *et al*., 2023). Applying aqueous coriander extract as a sole herbal antioxidant in chicken patties has demonstrated its effectiveness in lowering TBARS levels and preserving product quality over a 9-day storage period at 4°C (Ahmad *et al*., 2023). No studies have explored using coriander powder to preserve meat quality post-gamma irradiation. Therefore, this study aimed to assess chicken meat's chemical characteristics and texture when treated with coriander powder and exposed to gamma irradiation.

MATERIALS AND METHODS

Study Area

The study was conducted at two distinct locations: the gamma irradiation site and the laboratory analysis site. Gamma irradiation was carried out at the Directorate of Laboratory Management, Research Facilities, and Science and Technology Park, located in the Ahmad Baiquni Science and Education Area of BRIN, Sleman, Special Region of Yogyakarta, Indonesia, at coordinates 110° 24' 50.98" south longitude and -7° 46' 40.88" east latitude. Laboratory analysis was conducted at the Umar Anggara Jenie Science and Technology Area of BRIN, Gunungkidul, Special Region of Yogyakarta, at coordinates 110° 33' 22.23" south longitude and -7° 54' 43.73" east latitude.

Sample Preparation and Experimental Design

Fresh chicken breast fillets were obtained from modern market in Yogyakarta, Indonesia. Desaku®-branded coriander (*Coriandrum sativum*) powder was employed for the study. The experimental design was a completely randomized factorial pattern. The primary factors included the incorporation of coriander powder (CP) at 0% and 3% dry matter (DM), as well as gamma radiation dosages of 0, 1, and 2 kGy. Observations were recorded at 0, 7, and 14 days of storage, with samples stored at a chilling temperature of 4°C.

Gamma Irradiation Treatment

Chicken meat samples (8 cm x 4 cm x 1 cm), with and without added coriander, were sealed in vacuum plastic packaging. The samples were stored in a container with ice packs to ensure freshness. Irradiation was performed at room temperature using a Gamma Cell 220 (Atomic Energy of Canada, Ottawa, Canada) with a ^{60}Co gamma source at a dose rate of 2.388 kGy per hour. The absorbed dose was measured using Harwell Amber and Red Perspex dosimeters (England).

Morphological Evaluation

Morphological observation was carried out through two methods: 1) visual inspection using a conventional camera and 2) examination with a scanning electron microscope (SEM) at magnifications of 500x, 1000x, and 2000x. Visual inspection was performed on meat samples after irradiation, and the samples were placed in a petri dish and photographed. Similarly, observations were conducted on post-storage samples on days 7 and 14.

A SEM was utilized to examine the morphological characteristics of the samples. The chicken meat samples were dried in a vacuum oven at 105°C for 72 hours. The dried samples were then placed on a palladium and gold-coated plate to ensure conductivity during observation. An acceleration energy of 15 kV facilitated the observations. The structure and particle distribution were meticulously examined at magnifications 500 and 2000 times.

Texture Measurement

The texture of samples was analysed using a TA.XTplusC Texture Analyzer (Godalming, Surrey, UK). Meat samples measuring 3 cm x 3 cm x 1 cm were tested with a P/6 probe, which was pressed twice. The probe operated at a speed of 5 mm/s, reaching approximately 30% of the sample's height. The parameters measured included firmness, hardness, springiness, gumminess, and chewiness. Data calculations were derived from the Exponent Connect Texture Analysis software, which was linked to the instrument.

Color Measurement

Color parameters were assessed using samples measuring 3 cm x 2 cm x 1 cm, which were placed in a petri dish. A Konica Minolta chromameter (Konica Minolta, Tokyo, Japan) was employed to determine color, which was expressed in terms of brightness (L^*), redness (a^*), and yellowness (b^*).

Chemical Content Evaluation

The chemical composition of the samples was evaluated for water activity, moisture, fat, protein, and minerals. Water activity was measured using a Decagon Pawkit Water Activity Meter (Decagon Devices, Washington, US). Moisture content was analyzed with an MB120 Moisture Analyzer (OHAUS Instruments, Shanghai, China) for approximately 30 minutes. The protein and fat contents were determined following the method described in AOAC (AOAC, 2005). Mineral content was assessed using X-ray fluorescence (XRF). The meat sample was placed in a pellet press to ensure uniform vacuuming and then exposed to 50 kV X-rays. Each sample measurement, conducted with the Panalytical Epsilon 4 (Malvern, UK), took around eight minutes to complete.

Statistical Analysis

Two coriander powder doses, three irradiation doses, and three storage durations were replicated three times. The data were analyzed via one-way analysis of variance (ANOVA) using SPSS 23.0 (IBM, Armonk, New York, USA). Duncan's multiple range test was used to separate the means. We employed a General Linear Model (Univariate) to assess the statistical significance of the treatments and their interactions. Significant differences were identified at a significance level of $p < 0.05$ (Steel and Torrie, 1960).

RESULTS AND DISCUSSIONS

Morphological Attributes

Figure 1A illustrates the visual characteristics of chicken meat subjected to gamma irradiation and stored for 0, 7, and 14 days. In contrast, Figure 1B displays chicken meat pre-treated with CP prior to gamma irradiation. Visually, the addition of CP resulted in a darker coloration. Gamma irradiation did not visibly alter the appearance of fresh chicken meat or that treated with CP. As storage time progressed, the chicken meat exhibited a lighter color.

Food irradiation involves the use of radiation energy, which propagates through matter as invisible waves, to eliminate microorganisms present in food products (Ahn *et al*., 2013). Fallah *et al*. (2023) stated that food irradiation is a non-thermal preservation method, where pre-packaged or bulk products are exposed to precise doses of ionising radiation. This technique extends the shelf life of food, ensuring a safer and more durable supply for human consumption. Gamma irradiation, as a non-thermal preservation method, has been demonstrated to cause minimal alterations to the visual appearance of chicken meat, regardless of whether it is subjected to control treatments or supplemented with CP. Color changes are observed exclusively in treatments involving the addition of CP and during the storage period. Limited research has been conducted on the visual characteristics of chicken meat subjected to gamma irradiation in combination with the addition of herbs.

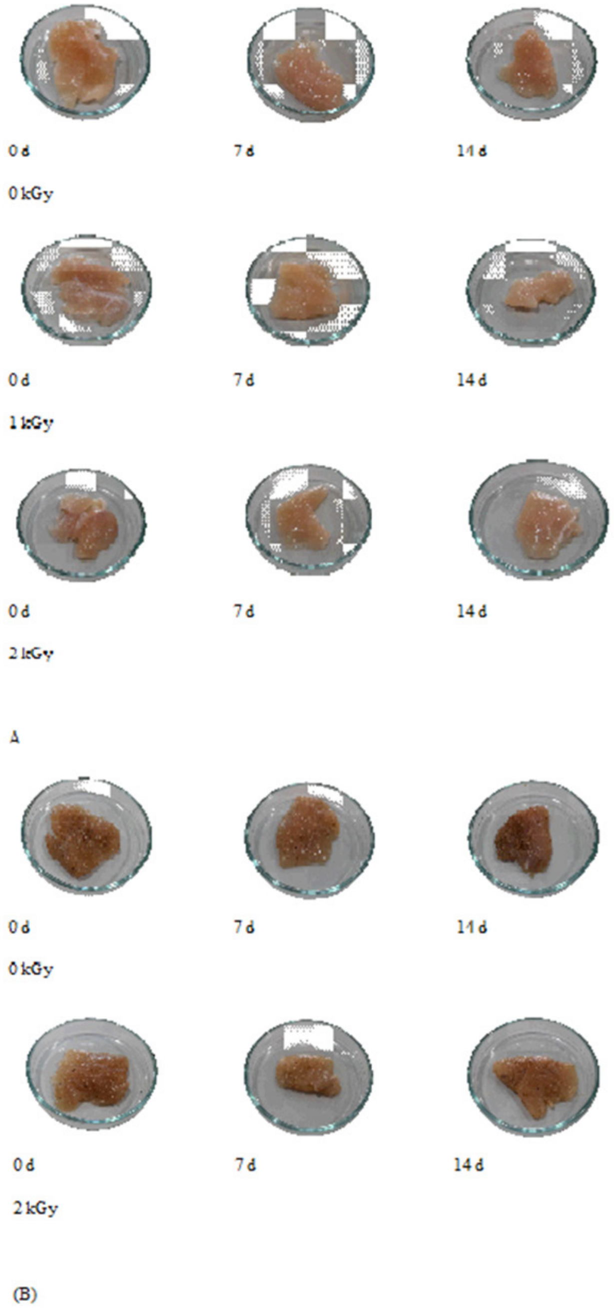

Figure 1: Visual comparison of irradiated chicken meat: without (A) and with (B) coriander addition.

Thus, comparisons with prior studies are relevant when evaluating appearance parameters in sensory assessments. A previous meta-analysis (Asmarani *et al*., 2024) concluded that gamma irradiation had no significant impact on the appearance parameters of chicken meat and its derivatives. Similarly, studies by Balamatsia *et al*. (2006), Fallah *et al*. (2010) and Khalid *et al*. (2021) reported minimal changes in the visual attributes of chicken meat following gamma irradiation. However, changes in appearance were observed when herbs, such as kale leaf powder (Khalid *et al*., 2021) or turmeric powder (Arshad *et al*., 2019), were applied. The discussion on meat color alterations after storage will be addressed under the section on color characteristics.

The morphological characteristics observed through SEM at magnifications of 500x and 2000x are presented in Figures 2 and 3. At 500x magnification, CP on chicken meat is distinctly visible, with a herbal-like texture partially covering the sample surface. SEM analysis reveals that gamma irradiation on meat without CP alters the surface morphology, making it rougher. In contrast, the addition of CP helps preserve a smoother meat surface.

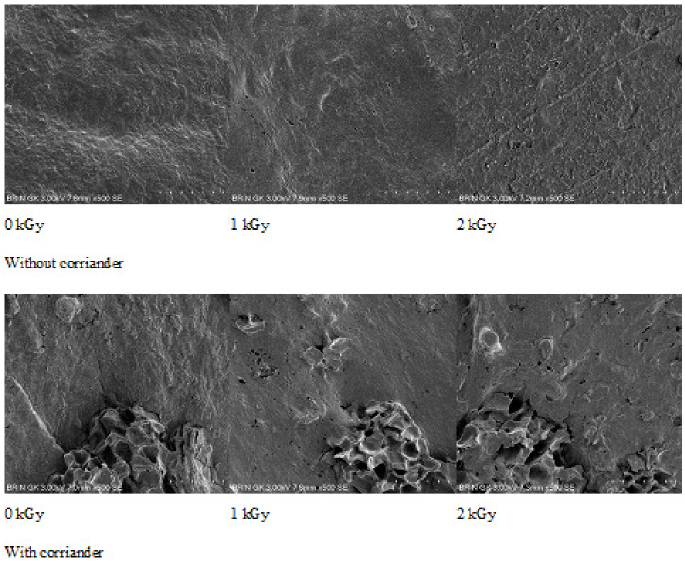

Figure 2: Morphological comparison by Scanning electron microscopy (SEM) of irradiated chicken meat: without and with coriander addition at 500x magnification.

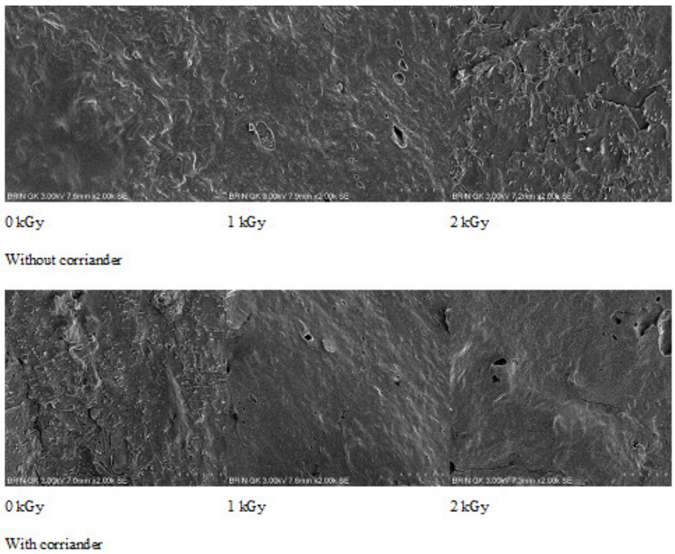

Figure 3: Morphological comparison by Scanning electron microscopy (SEM) of irradiated chicken meat: without and with coriander addition at 2000x magnification.

Figures 2 and 3 illustrate the chicken meat samples after treatment using a vacuum oven. Scanning electron microscopy (SEM) analysis was conducted to examine the microstructural characteristics of chicken meat subjected to various treatments. The application of CP to chicken meat appears to preserve its microstructural integrity, resulting in a smoother texture following gamma irradiation. Coriander leaves, which are abundant in volatile compounds such as limonene, geraniol, and linalool, exhibit antibacterial, antifungal, and antioxidant properties (Ahmad *et al*., 2023). CP's antioxidant capabilities have been demonstrated to effectively shield chicken meat from lipid oxidation post-irradiation, thereby enhancing the stability of fat globules. The softer microstructure may be attributed to the role of CP in preserving the stability of meat's water content during irradiation.

Table 1: Significance value of gamma irradiation treatment, coriander powder, storage period and their interactions.

	Texture characteristics				
	Firmness	Hardness	Springiness	Gumminess	Chewiness
I	0.943	0.001	0.001	0.001	0.001
CP	0.001	0.059	0.076	0.274	0.001
SP	0.002	0.317	0.062	0.015	0.001
I*CP	0.345	0.553	0.133	0.179	0.067
I*SP	0.018	0.355	0.097	0.805	0.030
CP*SP	0.743	0.149	0.488	0.792	0.029
			Color characteristics		
			L*	a*	b*
I			0.784	0.895	0.433
CP			0.004	0.001	0.001
SP			0.001	0.010	0.056
I*CP			0.798	0.508	0.607
I*SP			0.889	0.351	0.733
CP*SP			0.723	0.305	0.245
		Nutrient characteristics			
		Water activity	Moisture	Fat	Protein
I		0.076	0.541	0.540	0.012
CP		0.765	0.012	0.286	0.001
SP		0.001	0.371	0.084	0.040
I*CP		0.310	0.700	0.001	0.002
I*SP		0.954	0.679	0.001	0.284
CP*SP		0.925	0.143	0.309	0.001

I: gamma irradiation; **CP:** coriander powder; **SP:** storage period; **I*CP:** interaction between gamma irradiation and coriander powder; **I*SP:** interaction between gamma irradiation and storage period; **CP*SP:** interaction between coriander powder and storage period.

Oxidation levels are known to influence the water-holding capacity of meat. Well-bound water serves as a protective barrier for sensitive molecules, such as lipids and proteins, against free radicals generated during irradiation. These interactions, originating from the radiolysis of water, can lead to increased hydrogen peroxide formation (Brewer, 2009). Among the tested treatments, the addition of coriander extract yielded the highest water-holding capacity, outperforming the trypsin enzyme and ginger extract treatments (Kazem and Abdulrahem, 2024).

Texture Characteristics

The statistical analysis of texture parameters is summarized in Table 1, while the comparison of average treatment outcomes is detailed in Table 2. Except for firmness, all texture parameters were significantly influenced by gamma irradiation treatment ($p < 0.01$). The addition of CP notably enhanced both firmness and chewiness ($p < 0.01$). Regarding storage duration, chicken meat stored for 7 or 14 days exhibited reduced gumminess and chewiness compared to meat stored on day 0 ($p < 0.001$). An interaction effect was observed between gamma irradiation treatment and storage duration on firmness and chewiness ($p < 0.05$). Similarly, an interaction between CP and storage duration was noted for chewiness ($p < 0.05$). The highest firmness values (1.16 and 1.14 N) were observed in chicken meat subjected to gamma irradiation with CP treatment and stored for 14 days; however, these values were not significantly different from those in most other CP treatments. According to Table 2, gamma irradiation tends to reduce the hardness of the meat in both CP and non-CP treatments, while the springiness value shows a tendency to increase. The gumminess and chewiness values generally decrease following gamma irradiation, irrespective of CP addition. Gamma irradiation of chicken meat without CP resulted in reductions in gumminess and chewiness by approximately 31.95% and 21.62%, respectively, whereas the reductions in the CP treatment group were limited to about 16.09–16.38%.

In addition to visual and microstructural evaluations, texture analysis is essential for assessing the firmness, hardness, springiness, gumminess, and chewiness of chicken meat. Gamma irradiation, with or without the addition of CP, significantly alters most texture properties in chicken meat. This aligns with the findings compiled in our previous study (Asmarani *et al*., 2024), which reported that gamma irradiation impacts various sensory attributes (such as appearance, texture, taste, and odor) primarily on the initial day of storage or immediately after the irradiation process. Texture alterations in meat following gamma irradiation can be attributed to: (1) the degradation of myofibrillar and structural proteins (Rima *et al*., 2019), (2) the loss of moisture or liquid (Toledo *et al*., 2005), and (3) the breakdown of connective tissues within the meat (Indiarto *et al*., 2023). Gamma irradiation influences the tenderness of myofibrillar proteins by reducing their solubility

Table 2: Texture characteristics of chicken meat treated with gamma irradiation and coriander powder at different storage periods (0, 7th, and 14th days).

		Storage period (days)		
Parameter	**Treatments**	**0**	**7**	**14**
Firmness (N)	0 kGy	0.39 ± 0.03abcd	0.25 ± 0.07ab	0.41 ± 0.08abcd
	1 kGy	0.42 ± 0.08abcd	0.31 ± 0.04abc	0.55 ± 0.07bcdef
	2 kGy	0.53 ± 0.14abcde	0.19 ± 0.05a	0.60 ± 0.09cdef
	0 kGy + CP	1.18 ± 0.16h	1.01 ± 0.26gh	0.77 ± 0.11efg
	1 kGy + CP	0.88 ± 0.14fgh	0.81 ± 0.32efg	1.16 ± 0.35h
	2 kGy + CP	0.84 ± 0.15efgh	0.70 ± 0.09defg	1.14 ± 0.39h
Hardness (g)	0 kGy	13.39 ± 0.13bcd	12.93 ± 0.30abcd	12.49 ± 0.14ab
	1 kGy	12.35 ± 0.38ab	12.25 ± 0.42ab	11.77 ± 0.64a
	2 kGy	12.89 ± 0.29abcd	11.89 ± 1.11a	12.37 ± 0.24ab
	0 kGy + CP	12.88 ± 0.46abcd	13.95 ± 1.41d	13.69 ± 1.00cd
	1 kGy + CP	12.59 ± 0.25abc	12.24 ± 0.46ab	12.16 ± 0.77a
	2 kGy + CP	12.72 ± 0.28abc	12.41 ± 0.22ab	12.52 ± 0.51ab
Springiness (%)	0 kGy	106.01 ± 9.01ab	101.51 ± 7.99a	112.17 ± 1.65c
	1 kGy	112.28 ± 0.53c	112.27 ± 0.97c	113.37 ± 1.45c
	2 kGy	113.20 ± 0.67c	113.33 ± 0.25c	113.09 ± 1.39c
	0 kGy + CP	111.04 ± 0.25bc	108.95 ± 4.63bc	112.04 ± 0.95c
	1 kGy + CP	112.12 ± 0.93c	113.16 ± 0.63c	113.66 ± 0.88c
	2 kGy + CP	113.39 ± 1.06c	113.42 ± 0.88c	113.69 ± 1.45c
Gumminess (g)	0 kGy	28.68 ± 7.53d	21.43 ± 3.18abc	24.59 ± 11.08bcd
	1 kGy	19.28 ± 1.49abc	16.98 ± 1.73a	15.84 ± 1.26a
	2 kGy	18.99 ± 0.57abc	15.26 ± 0.57a	16.59 ± 1.98a
	0 kGy + CP	26.06 ± 2.94cd	22.46 ± 3.00abcd	21.47 ± 3.05abc
	1 kGy + CP	21.61 ± 2.17abc	18.07 ± 2.14ab	19.26 ± 2.18abc
	2 kGy + CP	19.96 ± 1.58abc	18.83 ± 2.36ab	19.94 ± 2.39abc
Chewiness (g)	0 kGy	27.61 ± 4.57f	24.16 ± 3.89def	19.70 ± 0.01abc
	1 kGy	21.63 ± 1.66abcd	18.05 ± 1.28ab	17.37 ± 1.22a
	2 kGy	20.89 ± 0.73abcd	17.57 ± 0.89a	17.55 ± 0.27a
	0 kGy + CP	26.67 ± 2.75ef	23.95 ± 1.90cdef	22.13 ± 0.49bcd
	1 kGy + CP	23.93 ± 2.91cdef	20.49 ± 2.75abcd	22.77 ± 1.08cde
	2 kGy + CP	22.31 ± 2.05bcd	20.46 ± 1.64abcd	24.29 ± 3.32def

CP: coriander powder; Different letters in the same row or column indicate significant differences.

in chicken meat, a phenomenon that exhibits a dose-dependent relationship with the applied radiation (Zhang *et al*., 2020; Kim *et al*., 2024). Ionizing energy disrupts protein bonds, leading to partial or complete denaturation of proteins in skeletal muscle and connective tissue (Choi *et al*., 2011) The rise in collagen solubility following gamma irradiation contributes to reducing meat's hardness, chewiness, and gumminess. As a predominant connective tissue protein, collagen significantly influences meat tenderness and texture (Kanatt *et al*., 2015). Research on pork irradiation has demonstrated that proteolysis and protein oxidation are key factors influencing the enhancement of tenderness in irradiated meat over storage duration (Zhang *et al*., 2020). Beyond alterations in protein components, the reduction in hardness and chewiness parameters is attributed to changes in the fatty acid composition of meat following irradiation. Gamma irradiation has been shown to modify the fatty acid profile of meat and its products (Asmarani et al., 2024).

Although irradiation led to a reduction in hardness, gumminess, and chewiness, careful handling is crucial to prevent tenderness, which may adversely affect meat quality. In this study, the incorporation of CP was employed to

Table 3: Color characteristics of chicken meat treated with gamma irradiation and coriander powder at different storage periods (0, 7th, and 14th days).

		Storage period (days)		
Parameter	**Treatments**	**0**	**7**	**14**
*L**	0 kGy	35.60 ± 2.49abc	44.45 ± 10.57bcd	45.03 ± 8.77cd
	1 kGy	35.07 ± 3.20abc	46.82 ± 8.13cd	51.22 ± 14.63d
	2 kGy	35.23 ± 7.58abc	47.43 ± 4.79cd	43.38 ± 8.80abcd
	0 kGy + CP	28.58 ± 3.93a	42.33 ± 10.52abcd	34.73 ± 8.81abc
	1 kGy + CP	29.50 ± 8.69ab	39.92 ± 3.19abcd	38.92 ± 8.08abcd
	2 kGy + CP	32.40 ± 5.40abc	40.15 ± 4.51abcd	39.93 ± 6.59abcd
*a**	0 kGy	7.15 ± 1.20a	9.57 ± 2.35abcd	9.00 ± 2.83abc
	1 kGy	7.23 ± 0.74a	8.53 ± 2.68ab	9.50 ± 2.69abcd
	2 kGy	8.48 ± 0.18ab	7.63 ± 1.68a	7.98 ± 0.24a
	0 kGy + CP	9.67 ± 2.02abcd	13.33 ± 2.20de	13.08 ± 4.60cde
	1 kGy + CP	10.32 ± 2.45	12.58 ± 0.33bcde	15.17 ± 1.72e
	2 kGy + CP	12.27 ± 1.55bcde	12.80 ± 0.62cde	14.60 ± 3.64e
*b**	0 kGy	2.60 ± 0.95abc	2.20 ± 1.22ab	2.93 ± 0.84abcd
	1 kGy	1.97 ± 0.60a	2.15 ± 0.76ab	2.52 ± 0.14abc
	2 kGy	3.00 ± 1.23abcde	2.68 ± 0.38abc	2.70 ± 0.79abc
	0 kGy + CP	4.03 ± 0.68cdefg	4.33 ± 0.71defg	4.80 ± 1.32fg
	1 kGy + CP	3.63 ± 1.04bcdef	4.58 ± 0.95efg	5.42 ± 0.24g
	2 kGy + CP	4.35 ± 0.38defg	4.47 ± 1.05defg	5.22 ± 0.72fg

***L**:** lightness; ***a**:** redness; ***b**:** yellowness; **CP:** coriander powder; Different letters in the same row or column indicate significant differences.

sustain meat tenderness and preserve its fresh appearance. This is evidenced by a 50% decrease in gumminess observed in CP-treated samples following irradiation. These results are consistent with the findings of Choi *et al.* (2011) and Kim *et al.* (2014), who investigated using kimchi as a supplementary treatment in meat irradiation. The application of herbs and spices, recognized for their antioxidant properties, can effectively stabilize meat texture during irradiation processes (Arshad *et al.*, 2019). Additionally, the inclusion of CP demonstrated a propensity to maintain textural stability throughout the storage period.

Color Characteristics

The outcomes of the statistical analysis regarding the effects of the three treatment factors on color parameters are presented in Table 1. Furthermore, the mean values across treatments are detailed in Table 3. Gamma irradiation did not significantly influence the *L**, *a**, and *b** parameters of chicken meat. Conversely, the addition of CP caused a significant reduction in the *L** value ($p < 0.01$), while significantly increasing the *a** and *b** values ($p < 0.01$). Extended storage duration increased both *L** and a* values ($p < 0.01$) but had no significant impact on the *b** value. Furthermore, no interactions were observed between the three treatment factors. The CP addition treatment without irradiation on day 0 of storage resulted in the lowest *L** value (28.58), although this was not statistically different from other CP addition treatments. On the same day, untreated chicken meat exhibited the lowest *a** value (7.15). Meanwhile, the highest *b** value (5.42) was observed in the chicken meat subjected to 1 kGy irradiation combined with CP addition after 14 days of storage.

The lack of color alteration in chicken meat post-irradiation aligns with findings from our previous meta-analysis (Asmarani *et al.*, 2024). This phenomenon occurs due to the low myoglobin (Mb) content in chicken meat, minimizing the impact of Mb oxidation (Zhou *et al.*, 2010). White meats like turkey and chicken breast contain higher levels of haemoglobin compared to myoglobin. Therefore, when evaluating pigment formation caused by irradiation in poultry meat, haemoglobin derivatives are likely to play a more significant role than myoglobin derivatives (Millar *et al.*, 2000). According to the underlying mechanisms (Hwang *et al.*, 2015; Reddy *et al.*, 2015; Asmarani *et al.*, 2024) , prolonged exposure and higher irradiation doses lead to the oxidation of Mb into MMb. During this process, irradiating meat with MMb facilitates MbO_2 regeneration, where MMb interacts with free radicals. When purified MMb is irradiated in an aqueous solution, only a small quantity of MbO_2 is generated. Consequently, as MbO_2

Table 4: Water activity, moisture, fat of chicken meat treated with gamma irradiation and coriander powder at different storage periods (0, 7th, and 14th days).

		Storage period (days)		
Parameter	**Treatments**	**0**	**7**	**14**
Water activity	0 kGy	0.992 ± 0.002abcde	0.988 ± 0.002a	0.988 ± 0.002a
	1 kGy	0.994 ± 0.004de	0.991 ± 0.001abcde	0.990 ± 0.004abcde
	2 kGy	0.994 ± 0.001de	0.992 ± 0.002abcde	0.989 ± 0.002ab
	0 kGy + CP	0.993 ± 0.003cde	0.991 ± 0.002abcde	0.988 ± 0.002a
	1 kGy + CP	0.993 ± 0.002cde	0.990 ± 0.003abcde	0.989 ± 0.001ab
	2 kGy + CP	0.993 ± 0.001cde	0.991 ± 0.001abcde	0.989 ± 0.004ab
Moisture (%)	0 kGy	56.72 ± 2.73	53.87 ± 2.38	52.15 ± 2.58
	1 kGy	57.06 ± 0.81	57.18 ± 2.45	52.19 ± 0.62
	2 kGy	55.51 ± 1.29	56.67 ± 1.34	55.38 ± 0.59
	0 kGy + CP	53.03 ± 5.89	53.24 ± 2.17	51.53 ± 1.42
	1 kGy + CP	54.28 ± 1.50	51.63 ± 5.49	54.98 ± 1.57
	2 kGy + CP	52.24 ± 4.14	51.81 ± 4.80	53.70 ± 5.26
Fat (%)	0 kGy	0.96 ± 0.01e	0.53 ± 0.06abc	0.60 ± 0.16bc
	1 kGy	0.51 ± 0.16ab	0.55 ± 0.14abc	0.52 ± 0.10ab
	2 kGy	0.35 ± 0.07a	0.53 ± 0.11abc	0.64 ± 0.15bcd
	0 kGy + CP	0.56 ± 0.17abc	0.50 ± 0.12ab	0.49 ± 0.04ab
	1 kGy + CP	0.69 ± 0.01bcd	0.61 ± 0.15bc	0.74 ± 0.11cd
	2 kGy + CP	0.51 ± 0.06ab	0.57 ± 0.12abc	0.82 ± 0.05de
Protein (%)	0 kGy	26.35 ± 0.26c	25.84 ± 0.85c	23.86 ± 0.57ab
	1 kGy	24.13 ± 0.04b	23.29 ± 0.32ab	23.62 ± 0.81ab
	2 kGy	26.22 ± 0.10c	23.91 ± 1.12ab	22.59 ± 0.32a
	0 kGy + CP	22.59 ± 0.16a	23.78 ± 0.30ab	23.97 ± 0.27ab
	1 kGy + CP	23.07 ± 0.49ab	24.16 ± 0.93b	23.65 ± 1.13ab
	2 kGy + CP	22.55 ± 0.77a	23.93 ± 1.67ab	23.86 ± 0.68ab

CP: coriander powder; Different letters in the same row or column indicate significant differences.

and MMb levels increase, the red color of the meat undergoes visible changes. Khalid *et al.* (2021) observed a reduction in L^* and a^* values following gamma irradiation of ostrich meat. This phenomenon is attributed to the inherently redder nature of ostrich meat compared to chicken, making the oxidative changes in myoglobin (Mb) more noticeable. Studies conducted by Millar *et al.* (2000), Ahn *et al.* (2008), and Brito *et al.* (2011) revealed conflicting findings, with notable changes—particularly reductions in the a^* value—observed in gamma-irradiated chicken meat. These variations may result from differences in the specific chicken parts subjected to irradiation, as highlighted by Brito *et al.* (2011). The current study selected breast meat fillets to ensure sample consistency. Furthermore, the irradiation dose plays a significant role in influencing oxidative responses in meat (Triyannanto *et al.*, 2024).

In our study, incorporating CP led to significant alterations in the L^*, a^*, and b^* values of chicken meat. This effect can be attributed to the introduction of color pigments derived from the added herbs or spices, with the extent of color change depending on the specific characteristics of the herbs used. Arshad *et al.* (2019) demonstrated that turmeric powder notably increased the L^*, a^*, and b^* values, while Khalid *et al.* (2021) observed a similar outcome with the addition of kale leaf powder. In our research, L^* and a^* values showed an increasing trend as storage time progressed at 4°C. This observation aligns with previous findings reported by Gomes *et al.* (2003), Brito *et al.* (2011), and Arshad *et al.* (2019). The observed color changes during storage can be attributed to the vulnerability of the myoglobin molecule, particularly its iron component, to chemical modifications and variations in energy input, which ultimately altered its state (Brewer, 2004; Brito *et al.*, 2011).

Chemical Content

The impact of irradiation, CP addition, and storage period on the nutritional properties of chicken meat is presented in Table 1. Table 4 outlines the average water activity and nutrient characteristics across 18 treatment combinations. Among the nutrient parameters, only protein content was influenced by gamma irradiation. Specifically, irradiation doses of 1 and 2 kGy resulted in significantly lower protein levels compared to the control ($p < 0.01$). The incorporation of CP was observed to decrease the moisture content of chicken meat ($p < 0.05$). Furthermore, water activity significantly declined as storage time increased ($p < 0.01$). An interaction effect between irradiation and CP addition was evident for fat content ($p < 0.01$), while an additional interaction was noted between CP addition and storage duration ($p < 0.01$). The water activity of chicken meat, both with and without CP addition, decreased during storage, reaching its peak on the 14th day. The moisture content did not differ significantly across the treatments. Fat content decreased in chicken meat subjected to irradiation without CP addition ($p < 0.05$). However, the inclusion of CP helped maintain fat stability, ranging from 0.51% to 0.69%, on day 0 of storage. A similar trend was observed for protein content; nevertheless, the addition of CP caused a reduction in protein levels on day 0 (26.35% vs. 22.59%; $p < 0.05$).

Post-irradiation interactions between free radicals and dietary components, including amino acids, lipids, and proteins, constitute a primary factor influencing alterations in product quality (Ferdousi *et al*., 2022; Khalid *et al*., 2023; Asmarani *et al*., 2024) . The findings of this study align closely with those of Al Bachir and Othman (2013) and Aly and El-Aragi (2013), who observed that gamma radiation doses of 2, 4, and 6 kGy had no impact on the nutritional composition or chemical properties of chicken sausages. Our findings revealed a significant reduction in the protein content of chicken meat following irradiation. Typically, irradiation impacts proteins through mechanisms such as amino acid oxidation, covalent bond disruption, rearrangement of secondary structures, and the generation of protein-free radicals. Furthermore, water hydrolysis induced by irradiation contributes to protein fragmentation, cross-linking, aggregation, and oxidation (Chen *et al*., 2016). A decline in protein and lipid content was observed across samples subjected to all applied irradiation doses (Al-Bachir *et al*., 2010). These alterations could be associated with a reduction in the hydration capacity of the protein fraction in meat, induced by gamma radiation (Baptista *et al*., 2014). Among food components, lipids are reported to be the most susceptible to irradiation. The lack of changes in lipid content may suggest the role of CP in mitigating lipid oxidation effects during irradiation. Contrasting findings were documented by Rima *et al*. (2019), who reported that gamma irradiation significantly influenced the nutritional quality of broiler meat. Their study indicated a notable increase in protein content following gamma irradiation ($p < 0.05$). These differences may be attributed to factors such as variability in the sampled meat parts, the initial moisture content of the meat, and the incorporation of herbs prior to irradiation. Nevertheless, further investigation is warranted to clarify these observations.

The inclusion of CP demonstrates efficacy in lowering the moisture content of meat, which subsequently enhances its ability to suppress microbial activity during storage. This effect is further substantiated by the observed reduction in water activity values following storage periods of 7 and 14 days. By decreasing moisture levels, CP effectively reinforces its roles as both an antioxidant and an antibacterial agent (Scandar *et al*., 2023). This effect might be further attributed to the application of vacuum packaging to chicken meat prior to storage. Kim *et al*. (2014) observed that storing Dry-Cured Pork Neck using vacuum packaging and modified atmosphere packaging effectively decreased the water activity during the storage period. Appropriate packaging and handling methods for beef have been shown to decrease its water activity levels, reducing them from 0.91 to 0.88 (Aykın-Dinçer and Erbaş, 2020).

The macro- and micromineral composition of chicken meat subjected to CP supplementation, gamma irradiation, and prolonged storage is outlined in Tables 5 and 6. After 14 days of storage, the lowest levels of potassium (K), sulfur (S), and phosphorus (P) were recorded ($p < 0.05$). Gamma irradiation had no notable effect on macromineral concentrations. However, CP addition significantly reduced sulfur levels ($p < 0.01$), whereas calcium (Ca) content markedly increased following CP addition ($p <0 .05$). The highest concentrations of K, S, and P, measuring 2.14%, 0.88%, and 0.76%, respectively, were observed in chicken meat irradiated at 1 kGy without CP addition. Furthermore, calcium levels increased by 4-6 times in chicken meat treated with CP, regardless of irradiation treatment ($p < 0.05$).

The administration of CP significantly reduced the chlorine (Cl) levels in chicken meat ($p < 0.05$). Additionally, storing the meat for 14 days further lowered the Cl concentration ($p < 0.05$). Zinc (Zn) levels were observed to decline significantly after 7 and 14 days of storage ($p < 0.05$). On the other hand, CP administration notably increased iron (Fe) content in the chicken meat ($p < 0.01$). No significant differences were detected between the treatment groups when mean values were analyzed. Furthermore, irradiation did not influence the micromineral profile of the chicken meat. On day 0, the highest Cl content (0.32–0.40%) was found in treatments without CP. There was no evidence of interaction effects among the three treatment factors. According to Indiarto *et al*. (2023), the impact of irradiation on the mineral composition of meat shows significant variability across studies, often manifesting as a reduction in specific minerals or no notable alterations. Hariyadi *et al*. (2023)

Table 5: Macrominerals of chicken meat treated with gamma irradiation and coriander powder at different storage periods (0, 7th, and 14th days).

		Storage period (days)		
Macrominerals	**Treatments**	**0**	**7**	**14**
K (%)	0 kGy	1.81 ± 0.25abcd	2.01 ± 0.14cd	1.48 ± 0.34ab
	1 kGy	2.14 ± 0.59d	1.83 ± 0.07abcd	1.49 ± 0.11abc
	2 kGy	2.02 ± 0.06cd	1.81 ± 0.07abcd	1.47 ± 0.56ab
	0 kGy + CP	1.88 ± 0.43abcd	1.69 ± 0.12abcd	1.56 ± 0.43abc
	1 kGy + CP	1.72 ± 0.06abcd	1.72 ± 0.18abcd	1.55 ± 0.02abc
	2 kGy + CP	2.04 ± 0.11cd	1.76 ± 0.18abcd	1.38 ± 0.18a
S (%)	0 kGy	0.67 ± 0.04cdefg	0.68 ± 0.13cdefg	0.47 ± 0.13abcd
	1 kGy	0.88 ± 0.28g	0.67 ± 0.05cdefg	0.49 ± 0.02abcde
	2 kGy	0.79 ± 0.09fg	0.64 ± 0.11cdef	0.46 ± 0.19abc
	0 kGy + CP	0.72 ± 0.21efg	0.51 ± 0.09abcde	0.35 ± 0.06a
	1 kGy + CP	0.66 ± 0.06cdefg	0.56 ± 0.11abcde	0.45 ± 0.05abc
	2 kGy + CP	0.74 ± 0.12efg	0.61 ± 0.10bcdef	0.40 ± 0.05ab
P (%)	0 kGy	0.57 ± 0.06abcde	0.60 ± 0.09bcde	0.39 ± 0.11ab
	1 kGy	0.76 ± 0.29e	0.56 ± 0.03abcde	0.40 ± 0.02ab
	2 kGy	0.68 ± 0.08de	0.55 ± 0.09abcde	0.39 ± 0.17ab
	0 kGy + CP	0.64 ± 0.19cde	0.48 ± 0.09abcd	0.37 ± 0.09a
	1 kGy + CP	0.56 ± 0.05abcde	0.51 ± 0.12abcd	0.41 ± 0.06abc
	2 kGy + CP	0.66 ± 0.07de	0.54 ± 0.03abcde	0.36 ± 0.04a
Ca (ppm)	0 kGy	547.01 ± 115.34a	470.60 ± 57.46a	612.53 ± 40.16a
	1 kGy	682.83 ± 343.27a	567.10 ± 115.88a	543.70 ± 51.88a
	2 kGy	642.57 ± 83.83a	396.97 ± 109.94a	449.37 ± 94.09a
	0 kGy + CP	2523.23 ± 200.33b	2539.67 ± 168.41b	2567.67 ± 401.87b
	1 kGy + CP	2123.33 ± 308.14b	2708.01 ± 278.09b	2415.67 ± 191.93b
	2 kGy + CP	2786.01 ± 997.479b	2353.01 ± 83.11b	2457.67 ± 116.09b

CP: coriander powder; Different letters in the same row or column indicate significant differences.

Table 6: Microminerals of chicken meat treated with gamma irradiation and coriander powder at different storage periods (0, 7th, and 14th days).

		Storage period (days)		
Microminerals	**Treatments**	**0**	**7**	**14**
Cl (%)	0 kGy	0.32 ± 0.08abcd	0.33 ± 0.03bcd	0.23 ± 0.09abc
	1 kGy	0.40 ± 0.12d	0.31 ± 0.03abcd	0.23 ± 0.05abc
	2 kGy	0.35 ± 0.04cd	0.31 ± 0.08abcd	0.22 ± 0.15abc
	0 kGy + CP	0.31 ± 0.12abcd	0.22 ± 0.05abc	0.19 ± 0.10ab
	1 kGy + CP	0.26 ± 0.03abcd	0.24 ± 0.04abcd	0.22 ± 0.06abc
	2 kGy + CP	0.31 ± 0.06abcd	0.27 ± 0.05abcd	0.18 ± 0.05a
Zn (ppm)	0 kGy	227.13 ± 59.12	172.63 ± 45.24	138.57 ± 55.26
	1 kGy	215.63 ± 45.42	176.57 ± 57.81	138.23 ± 59.33
	2 kGy	215.50 ± 33.08	201.20 ± 37.22	130.93 ± 43.03
	0 kGy + CP	215.13 ± 94.34	154.95 ± 32.46	130.57 ± 53.81
	1 kGy + CP	216.87 ± 96.94	125.23 ± 11.34	148.57 ± 64.52
	2 kGy + CP	183.57 ± 56.96	146.20 ± 38.88	157.27 ± 38.96
Fe (ppm)	0 kGy	116.77 ± 37.92abc	129.83 ± 27.76abc	105.40 ± 25.51ab
	1 kGy	225.97 ± 27.07c	91.73 ± 15.41a	86.01 ± 17.61a

	2 kGy	111.20 ± 11.98ab	101.27 ± 20.78ab	83.53 ± 11.06a
	0 kGy + CP	196.90 ± 29.03abc	186.23 ± 31.84abc	213.83 ± 86.41bc
	1 kGy + CP	125.80 ± 21.10ab	182.73 ± 23.05abc	187.63 ± 36.77abc
	2 kGy + CP	144.30 ± 21.10ab	161.20 ± 21.23abc	166.60 ± 31.85abc

CP: coriander powder; Different letters in the same row or column indicate significant differences.

suggested that this variability might stem from the reduction or eradication of microbial populations. The incorporation of CP into meat has been shown to enhance its calcium (Ca) and iron (Fe) content, attributed to the rich mineral profile of CP, which includes calcium, phosphorus, and iron (Mandal and Mandal, 2015).

CONCLUSIONS AND RECOMMENDATIONS

Incorporating coriander powder (CP) prior to gamma irradiation has been shown to preserve the smooth texture of chicken meat, as demonstrated through SEM analysis at 500x and 2000x magnifications. Similar to the impact of gamma irradiation, which diminishes gumminess and chewiness, the addition of CP does not disrupt this effect. Overall, parameters such as color and nutrient content remain unaffected by gamma irradiation, regardless of whether CP is included. Notably, calcium (Ca) levels increase following CP supplementation. Based on these findings, combined CP and gamma irradiation at a dosage of 1 kGy is recommended to sustain the texture and chemical properties of chicken meat during storage. However, this study has limitations, including the need for additional data to substantiate CP's role in mitigating lipid oxidation in gamma-irradiated chicken meat. Furthermore, assessing consumer acceptance of this product is essential.

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NOVELTY STATEMENT

This study utilized coriander powder (CP) to preserve the quality of meat subjected to gamma irradiation. To our knowledge, it represents the first investigation to combine CP with gamma irradiation as a preservation strategy. While prior research has explored various herbs to counteract the detrimental effects of gamma irradiation, such as lipid oxidation, this study emphasizes the morphological and chemical changes in chicken meat treated with CP. Incorporating CP is a practical and effective approach, given its widespread use as a traditional culinary spice.

AUTHOR'S CONTRIBUTIONS

Hariyadi: prepared the sample, performed laboratory analysis, collected the data, and wrote the first draft manuscript.
Rusman: supervised the experiment and revised the manuscript.
Triyannanto: designed and supervised the experiment, analyzed the data, and revised the manuscript.
Asmarani: prepared the sample, conducted chemical measurements, and analyzed the data.
Badrun: performed laboratory analysis, and analyzed the data.
Firmansyah: prepared raw sample and conducted chemical measurements.
Wahyono: designed and supervised the experiment, analyzed the data, visualization, wrote the first draft, and revised the manuscript.

Conflict of Interest

The authors declare there is no conflict of interest.

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