2026, Scienceline Publication
World's Veterinary Journal
World Vet J, 16(3): 808-817.
ISSN 2322-4568

DOI: https://dx.doi.org/10.54203/scil.2026.wvj75
PII: S2322456826000075-16

Physicochemical Characteristics of Sterilized Milk Supplemented with Mung Bean (*Vigna radiata* L.) Extract

Andi Ratna Dewi Sari[1], **Fatma Maruddin**[2*], **and Wahniyathi Hatta**[2]

[1]*Student of the Animal Science and Technology Study Program, Faculty of Animal Science, Hasanuddin University, Makassar 90245, Indonesia*
[2]*Faculty of Animal Science, Hasanuddin University, Makassar 90245, Indonesia*

**Corresponding author's Email: fatma_maruddin@unhas.ac.id*

ORIGINAL ARTICLE
Received: June 23, 2026
Revised: July 25, 2026
Accepted: August 17, 2026
Published: September 25, 2026

ABSTRACT

Sterilized milk is a nutritious dairy product; however, its dietary fiber and antioxidant contents are relatively low. Investigating the potential of sterilized milk is important to support the development of nutritionally enhanced and high-quality functional dairy beverages. The present study aimed to investigate the effects of incorporating mung bean (*Vigna radiata* L.) extract on the physicochemical properties, antioxidant activity, and dietary fiber content of sterilized milk. The present study followed a completely randomized design and consisted of four treatment groups with three replications per treatment. The first group was the control, with 100% milk and 0% mung bean extract (A1), the second group consisted of 80% milk and 20% mung bean extract (A2), the third group included 60% milk and 40% mung bean extract (A3), and the fourth group consisted of 40% milk and 60% mung bean extract (A4). Parameters analyzed included antioxidant activity, dietary fiber content, protein content, viscosity, and color (L*, a*, b*). The current results indicated that mung bean substitution had significant effects on all observed parameters. Increasing substitution levels increased antioxidant activity from 18.54% (A1) to 29.14% (A4), and dietary fiber content increased from 0.25% (A1) to 3.22% (A4). The highest protein content (2.28%) was achieved using a 20% mung bean extract substitution. Higher mung bean substitution increased the viscosity from 1.43 centipoise (cP) in the control group to 1.84 cP in Group A4. Compared to the control group, Group A4 exhibited a decrease in lightness (L*) from 74.80 to 66.90 and redness (a) from 5.61 to 0.58, alongside an increase in yellowness (b*) from 2.44 to 3.67. Substituting with 60% mung bean extract yielded the highest antioxidant activity and dietary fiber levels, while 20% mung bean extract led to the highest protein content.

Keywords: Antioxidant activity, Color value, Dietary fiber, Mung bean, Sterilized milk, Viscosity

INTRODUCTION

The demand for functional and nutritious food has risen as consumers have become increasingly aware of the correlation between diet and chronic health conditions (Żurek et al., 2026). Milk is a nutrient-dense food containing a wide range of essential nutrients; however, high-temperature sterilization processes can reduce some of its bioactive components. Bioactive components in milk are biologically active compounds that produce beneficial physiological effects as essential nutrients, such as proteins, fats, vitamins, and lactose (Kilic-Akyilmaz et al., 2022). Additionally, while cow's milk is high in protein and minerals, it naturally lacks dietary fiber (Antunes et al., 2022). Milk contains endogenous antioxidants that contribute to its nutritional and functional attributes. Moreover, the antioxidant capacity of milk can be improved by integrating natural plant-derived ingredients during milk processing (Stobiecka et al., 2022). Although the health advantages of dietary fiber are well-known, many adults worldwide still do not reach the recommended intake (Ioniță-Mîndrican et al., 2022). A recent systematic review and meta-analysis study revealed that adults in Indonesia and Malaysia consumed only 10.7%-72.7% of the advised dietary fiber intake, highlighting a significant gap compared to current dietary recommendations (Agustina et al., 2025). This condition underscores the importance of developing innovative food products enriched with dietary fiber to enhance nutrient intake and promote public health.

Mung bean (*Vigna radiata* L.) is regarded as a promising ingredient due to its high protein content (20.97%-32.6%; Tarahi, 2024), crude fiber levels ranging from 3.8% to 6.15% depending on the cultivar and geographical origin (Mehta et al., 2021), and the presence of bioactive compounds such as flavonoids, including vitexin and isovitexin, which demonstrate antioxidant activity (Desta et al., 2024). In addition, mung beans contain dietary fiber ranging from 14.57% to 24.5% (Yucel et al., 2025). Adding mung bean extract to sterilized milk is expected to enhance its nutritional profile by increasing protein content, antioxidant capacity (Zheng et al., 2020), and dietary fiber. However, this addition may affect different physicochemical properties of milk (Liu et al., 2025).

To cite this paper: Sari ARD, Maruddin F, and Hatta W (2026). Physicochemical Characteristics of Sterilized Milk Supplemented with Mung Bean (*Vigna radiata* L.) Extract. *World Vet. J.,* 16(3): 808-817. DOI: https://dx.doi.org/10.54203/scil.2026.wvj75

Previous studies have demonstrated the potential of plant-based ingredients to improve the functional quality of dairy products. Enriching goat milk yogurt with mung bean extract improved its physicochemical properties (Firmansyah et al., 2025), while the addition of *Moringa oleifera* extract enhanced the nutritional quality of cow's milk (Lisak Jakopović et al., 2022). Likewise, spinach powder has been successfully used as a functional ingredient in soft cheese production (El-Sayed, 2020). Overall, these studies indicated that plant-derived materials rich in phenolic compounds, flavonoids, and dietary fiber can enhance the functional properties of dairy products while influencing their physicochemical characteristics. However, limited information is available concerning the incorporation of mung bean extract into sterilized milk, specifically regarding its impact on antioxidant activity, dietary fiber, protein content, viscosity, and color subsequent to thermal sterilization. Accordingly, the present study aimed to assess the impact of mung bean substitution on the physicochemical characteristics of sterilized milk to develop a functional dairy beverage with improved nutritional and functional properties.

MATERIALS AND METHODS

Ethical approval

This study did not involve human participants or animals; therefore, ethical approval was not required. Also, the final product was not consumed by live humans, animals, or organisms.

Materials

The materials employed in the current study included Dancow® full-cream milk powder (PT. Nestle, Indonesia), distilled water (PT. Sumber Rejeki Berkat Abadi, Makassar, Indonesia), Lemovita® stevia (Lemovita, Indonesia), porang flour (Ikarie Organic®, Indonesia), mung beans purchased from a local market in Makassar, Indonesia, and Le Minerale® bottled drinking water from PT Tirta Fresindo Jaya, Indonesia. The equipment utilized included a stainless steel pan, thermometer, measuring cup, stirrer, sieve, autoclave (Tomy SX-500, Japan), stove, blender, spoon, scale, and Ostwald viscometer (Pyrex®, USA).

Experimental design

The present study utilized a completely randomized design (CRD) with four levels of mung bean extract substitution in sterilized milk formulations. The control group comprised 100% milk without any mung bean extract (A1), the second group consisted of 80% milk and 20% mung bean extract (A2), the third group consisted of 60% milk and 40% mung bean extract (A3), and the fourth group contained 40% milk and 60% mung bean extract (A4). Each treatment group was replicated three times, resulting in a total of 12 experimental units. The parameters observed in the present study included antioxidant activity, dietary fiber content, protein content, viscosity, and color characteristics such as L*, a*, and b* of milk.

Mung bean extract preparation

The mung bean extract was prepared following a modified procedure based on the study of Huang et al. (2024). Initially, the mung beans were sorted, after which 112.5 g were weighed and soaked in water at room temperature for eight hours. Following soaking, the beans were drained and boiled in water (12.5%, w/v) at 100°C for 15 minutes. The cooked beans were then blended until a homogeneous consistency was achieved and subsequently filtered through a filter cloth to obtain the mung bean extract. Finally, 0.1% (w/v) stevia was added and thoroughly mixed. Prior to formulation, the mung bean extract was characterized through laboratory analyses. The protein and dietary fiber contents were analyzed at the Makassar Public Health Laboratory (Labkesmas Makassar, Indonesia), while antioxidant activity was determined at the Laboratory of Animal Product Technology, Faculty of Animal Science, Universitas Hasanuddin, Makassar, Indonesia. The analysis revealed that the mung bean extract contained 1.18% protein, 2.27% dietary fiber, and exhibited 23.40% antioxidant activity.

Sterilized mung bean-fortified milk formulation

The sterilized milk substitute with mung bean extract was prepared by dissolving 13.5% (w/v) full-cream milk powder in drinking water according to the manufacturer's instructions, along with 0.1% (w/v) stevia, followed by homogenization. Mung bean extract was then added at 0%, 20%, 40%, and 60%, and the mixture was homogenized again. Porang flour was added at a constant concentration of 0.05% (w/v) in all formulations, followed by further homogenization to obtain a uniform mixture. The mixtures were then subjected to heat treatment in an autoclave at 105°C for five minutes. The chosen processing temperature was in accordance with the range specified for in-bottle milk sterilization guidelines (105-120°C) as documented by Melini et al. (2017), although the current study employed a shorter heating duration. This temperature-time combination was selected based on preliminary laboratory trials conducted prior to the main experiment, encompassing microbiological analysis by the Microbiology Faculty of Animal Science at Hasanuddin University, Makassar, Indonesia. This analysis confirmed that the treatment was adequate to ensure product safety under the conditions implemented in the present study.

Following thermal processing, the samples were cooled at room temperature for approximately 30 minutes prior to conducting physicochemical analyses (Yuan et al., 2023). The evaluated parameters included antioxidant activity, crude fiber, protein content, viscosity, and color attributes (L, a, and b*).

Antioxidant activity

Antioxidant activity was evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical-scavenging method. The DPPH reagent (0.2 mM) was prepared by dissolving 4 mg of DPPH in methanol and diluting to a final volume of 50 mL. A total of 1 mL of the DPPH reagent was combined with 1 mL of the sample solution at the respective concentrations. The mixture was incubated in the dark at room temperature for 30 minutes, after which absorbance was recorded at 517 nm using a UV-Vis spectrophotometer. The percentage of DPPH radical-scavenging activity was calculated according to de Menezes et al. (2021) using Formula 1. Antioxidant activity was expressed as the half-maximal inhibitory concentration (IC_{50}, µg/mL). The IC_{50} value was determined by linear regression of sample concentration against the percentage of DPPH radical inhibition. The IC_{50} value indicated the concentration of the sample necessary to attain 50% scavenging of DPPH radicals as well as 50% inhibition.

$$\text{Free radical scavenging activity (\%)} = \frac{\text{Absorbance of reagent blank-Absorbance of sample}}{\text{Absorbance of reagent blank}} \times 100\% \quad \text{(Formula 1)}$$

Crude fiber content

Crude fiber content was determined using the gravimetric method following sequential acid-alkali digestion according to AOAC official method (978.10; Thiex, 2009; Formula 2).

$$\text{Crude fibre (\%)} = \frac{W2\text{-}W1}{W} \times 100\% \qquad \text{(Formula 2)}$$

Where W1 was the weight of the empty filter paper (g), W2 was the weight of the filter paper containing the residue after oven drying (g), and W was the weight of the sample used for analysis (g).

Protein content

Protein content was analyzed according to the Kjeldahl method as described by Shivanna et al. (2025). The total nitrogen content was subsequently calculated using the following equation (Shivanna et al., 2025, Formulas 3 and 4).

$$\text{N (\%)} = \frac{14.007 \times (\text{V s - V b}) \times \text{Normality of sulphuric acid}}{\text{weight of sample (g))}} \times 100 \quad \text{(Formula 3)}$$

$$\text{Protein content (\%)} = \text{N (\%)} \times 6.38 \qquad \text{(Formula 4)}$$

Where Vs was the volume (mL) of 0.1 N H_2SO_4 titrant used for the test portion, and Vb was the volume (mL) of 0.1 N H_2SO_4 titrant used for the blank determination.

Viscosity

Viscosity was measured using an Ostwald viscometer in accordance with the procedures reported by Lewis (1990), as cited in Shivanna et al. (2025). The viscosity of each sample was expressed as absolute viscosity (cP) and determined at 27°C. Sample density was measured independently using a pycnometer at a consistent temperature, with a thermostatically controlled water bath employed to maintain a constant temperature of 27°C. Specific gravity (Formula 5), relative viscosity (Formula 6), and absolute viscosity (Formula 7) were determined using the following equations.

$$\text{Specific gravity} = \frac{\text{Weight of pycnometer fill with sample -Weight of empty pycnometer}}{\text{Weight of pycnometer fill with water -Weight of empty pycnometer}} \qquad \text{(Formula 5)}$$

$$\text{Relative viscosity} = \frac{A}{B} \times \text{specific gravity} \qquad \text{(Formula 6)}$$

Where A represented the flow time of the sample from the upper tip to the lower mark of the Ostwald viscometer, and B represented the corresponding flow time of water measured under the same conditions.

$$\text{Absolute viscosity} = \text{Relative viscosity} \times \text{viscosity of water at 27 °C} \qquad \text{(Formula 7)}$$

Color

Color characteristics were assessed utilizing the Hunter Lab color system. Within this system, the L* value indicates lightness, ranging from 0 (black) to 100 (white), whereas the a* value describes the red (+) to green (−) axis, and the b* value corresponds to the yellow (+) to blue (−) axis (Hasnul Hadi et al., 2021).

Statistical analysis

The data were analyzed using analysis of variance (ANOVA) within a completely randomized design (CRD) to assess the impact of mung bean extract substitution on various milk parameters. In cases where significant differences ($p < 0.05$) were identified, Duncan's multiple range test was utilized for mean comparison. All statistical analyses were conducted using SPSS software (version 24).

RESULTS AND DISCUSSION

Antioxidant activity

The current results indicated that mung bean extract substitution had a significant effect on the antioxidant activity of sterilized milk ($p < 0.05$; Table 1). The antioxidant activity increased proportionally with the incorporation of mung bean extract, reaching its highest value in Group A4. The observed increase in antioxidant activity indicated that mung bean extract effectively enhanced the antioxidant capacity of sterilized milk. The increase in antioxidant activity was attributed to bioactive compounds in mung bean extract, particularly polyphenols and flavonoids (An et al., 2024). Polyphenols and flavonoids are known to act as free radical scavengers and electron donors, thereby reducing oxidative reactions and neutralizing reactive oxygen species (ROS; Zhang and Huang, 2024). Furthermore, mung bean comprises bioactive compounds, including polysaccharides, which enhance its antioxidant activity (Hou et al., 2019). Therefore, increasing the proportion of mung bean extract increased the concentration of antioxidant compounds in the sterilized milk formulations, resulting in higher antioxidant activity. The observed improvement in antioxidant activity additionally indicated a synergistic effect between the antioxidant compounds inherently present in milk and those present in mung bean extract. Milk comprises different antioxidant components, including casein, whey proteins, and antioxidant vitamins such as vitamins A, C, and E (Stobiecka et al., 2022). The combination of milk antioxidant components with the phenolic compounds of mung bean extract may have contributed to the improved antioxidant potential of the sterilized milk. Previous studies have demonstrated that incorporating mung bean-derived ingredients enhanced antioxidant activity, primarily due to the high levels of phenolic and flavonoid compounds (Villanueva-Bermejo et al., 2024). These findings highlighted the suitability of mung bean extract as a functional ingredient for producing antioxidant-enriched sterilized milk.

Table 1. Antioxidant activity of sterilized milk substituted with mung bean extract

Mung bean extract substitution (%)	Antioxidant
0	18.54 ± 0.73^{a}
20	20.26 ± 0.45^{a}
40	22.96 ± 1.30^{b}
60	29.14 ± 1.90^{c}

Data are presented as mean ± standard deviation. [a,b,c] Mean different superscript letters in the same column indicate significant differences ($p < 0.05$).

Fiber content

The present results indicated that dietary fiber content increased significantly with increasing levels of mung bean extract substitution ($p < 0.05$; Table 2). Higher substitution levels resulted in greater fiber content, with the highest value observed in Group A4. The increase in dietary fiber level was primarily attributed to the naturally high dietary fiber content of mung beans (Sudhakaran and Bukkan, 2021). Previous studies have reported that mung beans are a rich source of dietary fiber, including soluble fiber, insoluble fiber, and resistant starch (Zafar et al., 2023; Chauhan et al., 2024). Consequently, increasing the proportion of mung bean extract added more indigestible carbohydrate components into the product, resulting in a progressive increase in fiber content. Besides dietary fiber, mung beans have high levels of resistant starch, which acts similarly to fiber by resisting digestion in the small intestine and undergoing fermentation in the colon (Chauhan et al., 2024). Resistant starch may improve the functional qualities of sterilized milk by providing more fermentable substrates for beneficial gut bacteria, thereby supporting digestive health. The higher dietary fiber content achieved through mung bean substitution highlighted its potential as a functional ingredient to enhance the nutritional profile of sterilized milk. Previous studies have indicated that dietary fiber contributed to several health-promoting effects, such as improved glycemic control, reduced serum cholesterol, greater satiety, and improved gastrointestinal function (Alahmari, 2024).

Table 2. Fiber content of sterilized milk substituted with mung bean extract

Mung bean extract substitution (%)	Fiber content
0	0.25 ± 0.09^{a}
20	1.32 ± 0.67^{b}
40	2.04 ± 0.15^{c}
60	3.22 ± 0.25^{d}

Data are presented as mean ± standard deviation. [a,b,c,d] Means different superscript letters in the same column indicate significant differences ($p < 0.05$).

Protein content

Mung bean extract substitution had a highly significant effect on the protein content of sterilized milk ($p < 0.05$; Table 3). Protein content demonstrated a non-linear response to increasing substitution levels, reaching its highest value in Group A2. This finding indicated that a moderate mung bean extract substitution level provided a favorable balance between the milk and plant proteins, whereas excessive substitution altered the protein composition of the final product.

Mung beans are known for their high protein content, ranging from 22-28%, along with a well-balanced essential amino acid profile (Yi-Shen et al., 2018). However, elevated substitution levels of mung bean extract did not correspondingly enhance the protein content of sterilized milk, which was likely due to the extract's greater water content and lower protein solids compared to whole milk. Plant proteins differ structurally from milk proteins, notably caseins and whey proteins, leading to variations in their functional properties, such as solubility (Tang et al., 2023). Consistent findings were reported by Firmansyah et al. (2025), who observed a progressive decrease in protein content from 3.46% (control) to 3.07% in goat milk yogurt substituted with 15-45% mung bean extract, an effect that was attributed to dilution due to the extract's lower protein concentration. The present results indicated that increasing mung bean extract substitution reduced protein content in dairy products, which was consistent with the findings of Firmansyah et al. (2025), although fermented yogurt was used in their study. When the mung bean substitution exceeds 20%, the reduction in protein content might be linked to physicochemical interactions that occurred during thermal processing. Mung bean extract contains phenolic compounds, polysaccharides, and dietary fiber that can interact with milk proteins. Protein-phenolic interactions occur via hydrogen bonds, hydrophobic interactions, and, under thermal conditions, covalent bonding following phenolic oxidation. Protein-phenolic interactions can cause conformational changes, promote aggregation, and decrease protein solubility, thereby modifying proteins' functional properties (Zhang et al., 2021a). In addition, sterilization at high temperatures promotes protein denaturation and aggregation, further intensifying these structural modifications (Huang et al., 2022).

Table 3. Protein content of the sterilized milk substituted with mung bean extract

Mung bean extract substitution (%)	Protein content
0	2.17 ± 0.05^{b}
20	2.28 ± 0.30^{b}
40	1.71 ± 0.17^{a}
60	1.69 ± 0.35^{a}

Data are presented as mean ± standard deviation. [a,b] Means with different superscript letters in the same column indicate significant differences ($p < 0.05$).

Viscosity

The present results indicated that mung bean extract substitution significantly affected the viscosity of sterilized milk and produced a thicker product ($p < 0.05$; Table 4). Viscosity increased progressively with increasing levels of mung bean extract substitution, with the highest value observed in Group A4.

The increase in milk viscosity was primarily associated with the higher concentration of total solids supplied by mung bean extract, including dietary fiber, starch, and other polysaccharides (Tarahi et al., 2024). These macromolecular components have a high water-binding capacity, allowing them to absorb and hold water within the system, which increases resistance to flow (Petronilho et al., 2021; Ariyarathna et al., 2025). As the level of mung bean extract increased, the amount of suspended and dissolved solids in the product increased, reducing the mobility of water molecules and consequently increasing viscosity.

Table 4. Viscosity of sterilized milk substituted with mung bean extract

Mung bean extract substitution (%)	Viscosity
0	1.43 ± 0.06^{a}
20	1.64 ± 0.05^{b}
40	1.72 ± 0.05^{bc}
60	1.84 ± 0.09^{c}

Data are presented as mean ± standard deviation. [a,b,c] Means with different superscript letters in the same column indicate significant differences ($p < 0.05$).

The observed increase in viscosity might be attributed to the thermal trait of starch during the sterilization process. Exposure to high temperatures can induce starch swelling and partial gelatinization, resulting in increased water retention and the development of a more structured system (Ariyarathna et al., 2025). Furthermore, interactions among milk proteins, polysaccharides, and dietary fiber may facilitate the formation of a more stable colloidal network, thereby improving the product's consistency and viscosity. The current findings suggested that mung bean extract can improve not only the nutritional value of sterilized milk but also its physical properties. The increase in viscosity may be beneficial for developing functional dairy beverages by improving body, texture, and product stability. Similar observations have been documented in previous studies, where the integration of plant-derived components rich in starch and dietary fiber led to an increase in the viscosity of milk-based beverages (Petronilho et al., 2021; Ariyarathna et al., 2025).

Color attributes

L value*

Mung bean extract substitution had a highly significant effect on the lightness (L*) of sterilized milk ($p < 0.05$; Table 5). The L* value decreased progressively with increasing levels of mung bean extract substitution, indicating a gradual reduction in product brightness. The highest L* value was observed in the control group, whereas the lowest L* value occurred in Group A4. These results demonstrated that increasing the proportion of mung bean extract produced a darker sterilized milk.

The reduction in lightness was primarily associated with the inherent color characteristics of mung bean extract, influenced by natural pigments and phenolic compounds present in the extract (Dahiya et al., 2015). The bright appearance of milk is largely attributed to light scattering by casein micelles and fat globules, which contribute to its whiteness and opacity characteristics (Serna-Hernandez et al., 2021). In contrast, mung bean extract contains several plant-derived compounds, including phenolic compounds and flavonoids, which may contribute to darker color development through the formation of dark-brown polymers and a reduction in lightness (L; Huang et al., 2022). Consequently, increasing the concentration of mung bean extract resulted in lower lightness. Thermal processing during sterilization may have further contributed to the decrease in lightness by promoting Maillard reactions and the formation of brown-colored compounds (Zhang et al., 2021b). High-temperature treatment can promote non-enzymatic browning reactions, particularly the Maillard reaction between reducing sugars and amino compounds, leading to the formation of brown-colored pigments (Huang et al., 2022). In addition, phenolic compounds from mung bean extract may undergo oxidation, degradation, and other heat-induced transformations during processing, which may further influence the product's color characteristics (Zhang et al., 2022).

The decline in L* values observed in the present study indicated that mung bean extract substitution not only enhanced the functional properties of sterilized milk but also modified its visual appearance. Similar reductions in lightness have been reported in milk-based beverages containing legume-derived ingredients, where increasing proportions of plant extracts altered the color characteristics of the products due to the presence of natural pigments (Kurbanova et al., 2024). The observed alterations in color parameters suggest that these color changes were a natural result of integrating mung bean extract into sterilized milk formulations. This finding reflected the contribution of plant-derived pigments and highlighted the successful incorporation of mung bean bioactive compounds into the dairy matrix.

Table 5. L* value of sterilized milk substituted with mung bean extract

Mung bean extract substitution (%)	Color attribute L
0	74.80 ± 0.79^{c}
20	72.85 ± 1.27^{bc}
40	72.29 ± 0.58^{b}
60	66.90 ± 1.39^{a}

Data are presented as mean ± standard deviation. [a,b,c] Means with different superscript letters in the same column indicate significant differences ($p < 0.05$).

a value*

These findings demonstrated that incorporating mung bean extract significantly affected the value, resulting in a greener appearance of the sterilized milk ($P < 0.05$; Table 6). The a* value decreased progressively with increasing levels of mung bean extract substitution, indicating a shift toward greener color tones.

The decrease in a* values may be attributed to the contribution of natural pigments in mung bean extract, notably chlorophyll and its derivatives, which influence the green-red color balance of plant-derived materials (Huang et al., 2022). Chlorophyll absorbs light in the red and blue regions of the visible spectrum while reflecting green wavelengths, thereby contributing to a greener appearance and reducing redness. Consequently, increasing the proportion of mung bean extract resulted in lower a* values and a more pronounced green hue in the sterilized milk. Thermal processing during sterilization further affected color by causing chlorophyll degradation and pigment transformations, as observed in heat-treated mung bean materials (Huang et al., 2022). High temperatures can convert chlorophyll into pheophytins and other pigments, affecting color expression while maintaining greenish or olive-green hues (Huang et al., 2022). In addition, interactions between chlorophyll compounds and other plant constituents may have affected the overall color stability of the product during processing. The shift toward greener color tones observed in the present study was related to the increasing concentration of mung bean-derived pigments in the formulation. Similar pigment-related color changes have been reported in mung bean-based products, where chlorophyll-derived pigments contributed to the green coloration and influenced the overall color characteristics during processing (Huang et al., 2022). These findings confirmed that mung bean extract not only enhanced the functional properties of sterilized milk but also produced a distinctive color profile that can serve as a visual indicator of successful plant-based fortification.

Table 6. *a value of sterilized milk substituted with mung bean extract

Mung bean extract substitution (%)	Color attribute *a
0	5.61 ± 0.27[d]
20	3.91 ± 0.17[c]
40	2.24 ± 0.16[b]
60	0.58 ± 0.93[a]

Data are presented as mean ± standard deviation. [a,b,c,d] Means with different superscript letters in the same column indicate significant differences ($p < 0.05$).

b* value

Mung bean extract substitution had a highly significant effect on the b* value of sterilized milk ($p < 0.05$; Table 7). Increasing the proportion of mung bean extract resulted in progressively higher b values, reflecting a greater degree of yellowness. Increasing the level of mung bean extract contributed to a progressive rise in the b* value, which was likely attributable to the carotenoid pigments naturally present in the extract (Zulueta et al., 2007). Mung bean contains carotenoid compounds, such as β-carotene, which are natural pigments that display yellow to orange hues (Maoka, 2020; Cheng et al., 2023). As a result, adding more mung bean extract led to a higher concentration of yellow pigments in the product, which increased the b* value.

Thermal processing during sterilization may have further contributed to the increase in yellowness. High-temperature treatment can promote pigment transformation and non-enzymatic browning reactions, leading to the formation of colored compounds that enhance yellow and brown color tones (Huang et al., 2022). In addition, the degradation of chlorophyll pigments during heating may reduce the intensity of green coloration and increase the visual prominence of yellow pigments, thereby contributing to a higher b* value.

The observed increase in yellowness (b*), coupled with decreased lightness (L*) and reduced redness (a*), indicated that mung bean extract significantly modified the visual appearance of sterilized milk. The current findings confirmed that mung bean extract not only improved the functional properties of sterilized milk but also established a color profile that can serve as a visual indicator of plant-based fortification and may increase product appeal to consumers in pursuit of functional dairy products.

Table 7. b* value of sterilized milk substituted with mung bean extract

Mung bean extract substitution (%)	Color attribute *b
0	2.44 ± 0.22[a]
20	2.88 ± 0.47[b]
40	3.28 ± 0.98[c]
60	3.67 ± 0.70[d]

Data are presented as mean ± standard deviation. [a,b,c,d] Means with different superscript letters in the same column indicate significant differences ($p < 0.05$).

CONCLUSION

Substituting mung bean extract with sterilized milk enhanced its functional quality and influenced its physicochemical characteristics. The highest level of mung bean substitution (60%) resulted in the greatest antioxidant activity, dietary fiber content, viscosity, and yellowness (b* value), while producing the lowest lightness (L* value) and the lowest redness (a* value), indicating a shift toward a darker, greener, and more yellow appearance. The highest protein content was obtained with 20% mung bean extract substitution. The current study demonstrated that adjusting the proportion of mung bean extract can be employed to achieve specific nutritional and functional characteristics in sterilized milk. Accordingly, mung bean extract can be used as an effective functional ingredient in the formulation of nutritionally enriched sterilized milk. Nevertheless, the present study was confined to the assessment of physicochemical characteristics and did not encompass an evaluation of shelf life, microbiological stability, or the interactions between calcium derived from milk and iron obtained from mung bean extract, including their retention and bioavailability. Consequently, further investigations are necessary to examine these parameters in order to provide a more comprehensive assessment of the product's nutritional value and storage stability.

DECLARATIONS

Acknowledgments

The authors would like to express their sincere appreciation to all parties who have supported the present study, directly or indirectly.

Authors' contributions

Andi Ratna Dewi Sari conceived the study, conducted the experiments, collected and analyzed the data, and prepared the original manuscript. Fatma Maruddin supervised the study, contributed to the study design, and critically reviewed and revised the manuscript. Wahniyathi Hatta contributed to data interpretation and critically reviewed the manuscript. All authors read and approved the final edition of the manuscript and agreed to be accountable for all aspects of the study.

Availability of data and materials

All data generated and analyzed during this study are presented in this manuscript, and no supplementary materials are associated with this article. Additional data are available from the corresponding author upon reasonable request.

Competing interests

The authors have not declared any conflict of interest.

Ethical considerations

Ethical issues, including plagiarism, consent to publish, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been checked by all the authors. All authors accept full responsibility for the originality of the data and the final edited version of the manuscript before submission and after the final proof prior to publication. The authors confirmed that no AI tools were used to prepare this study.

Funding

The present study received no external funding and was fully supported by the authors' personal resources.

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