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Formulation and Characterization of Lentil Milk–Based Soft Cheese Analogs: Insights on Physicochemical and Textural Properties

Hafsa Naeem[1] | Aqsa Akhtar[1] | Nadia Akram[2] | Hafiz Ansar Rasul Suleria[1,3] | Nauman Khalid[1,4]

[1]Department of Food Science and Technology, School of Food and Agricultural Sciences, University of Management and Technology, Lahore, Pakistan | [2]Faculty of Biological and Life Sciences, Kinnaird College for Women, Lahore, Pakistan | [3]School of Agriculture, Food and Ecosystem Sciences, Faculty of Sciences, The University of Melbourne, Parkville, Victoria, Australia | [4]College of Health Sciences, Abu Dhabi University, Abu Dhabi, UAE

Correspondence: Hafiz Ansar Rasul Suleria (hafiz.suleria@unimelb.edu.au) | Nauman Khalid (nauman.khalid@umt.edu.pk; nauman.khalid@adu.ac.ae)

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ABSTRACT

Lentil milk–based soft cheese (LBC) is one of the emerging partial substitutes for animal milk-based cheese. With time, more people want to reduce their meat and dairy intake for ethical, environmental, and chronic health–related concerns. This study focused on the formulation of LBC using milk extracted from green gram (S_1 (6.5 g) of proteins), red gram (S_2 (5 g) proteins), and black gram (S_3 (3.5 g) proteins). All formulated LBC samples were investigated by determining proximate analysis, syneresis, viscosity, texture, color change, storage time, microbial count, and sensory attributes to evaluate the quality during 15 days of storage. The results reported that pH levels decreased for both S_1 and S_3, while S_2 showed an increasing trend from Day 1 to Day 15. Viscosity and syneresis increased from Days 1 to 15 in S_1, S_2, and S_3. Moreover, assessment of storage stability showed significant changes ($p < 0.05$) in the microbial count for S_1 (7.89–4.98 CFU/mL), S_2 (2.88–9.68 CFU/mL), and S_3 (1.39–7.09 CFU/mL) from Day 1 to Day 15. The puncture force test reported that S_1 showed a decreasing trend while S_2 and S_3 showed an increasing trend. The color attributes also showed a rising trend across all LBC samples. For sensory evaluation, LBC prepared using green gram showed the highest scores, particularly in appearance, texture, and color. Overall findings concluded the potential of lentil milk as a suitable ingredient for plant-based soft cheese production, offering a new nutritious option for consumers with dietary preferences or restrictions.

1 | Introduction

Lentils have become a symbol of sustainable and nutritious eating practices, addressing various aspects of dietary needs and broader health and environmental concerns (Didinger and Thompson 2020). Lentils have shaped contemporary dietary patterns as a staple food in many cuisines worldwide. They offer a sustainable source of nutrition that aligns with changing dietary preferences, health considerations, and a growing focus on environmental sustainability (Mohiuddin, Akter, and Khanum 2018). Among many lentils, black gram (*Phaseolus mungo* L.), red gram (*Cajanus cajan* L.), and green gram or mung bean (*Vigna radiata* L.) hold significant importance for their direct consumption and use in various food products. The per capita lentil consumption in Asia was reported to be about 2,438,955 metric tons (Siddiq, Uebersax, and Siddiq 2022).

As a rich source of protein, with less saturated fat and fewer calories, lentils contribute to overall health and well-being while also significantly addressing nutritional challenges and food security (Kussmann, Abe Cunha, and Berciano 2023). Protein is an essential component of dairy milk, playing a significant role in nutritional value and the overall functionality of dairy-based milk foods (Swelum et al. 2021). However, the increasing prevalence of milk sensitivities, lactose intolerance, environmental concerns, allergens, and health issues among consumers of cholesterol-rich diets has led to a growing demand for nondairy alternatives. Although there are only a few dairy-free options available, there is a noticeable lack of choices for consumers (Taeger and Thiele 2024). Many individuals are shifting toward a lentil-based vegan diet, excluding animal-derived products, particularly milk. This dietary choice is driven by health consciousness, ethical considerations, and a desire for more sustainable food options (Enriquez and Archila-Godinez 2022).

Lentil-based milk substitutes have gained popularity recently, and various commercial products are widely processed (Reyes-Jurado et al. 2023). These substitutes hold immense potential as versatile ingredients in developing dairy-free cheese (Pua et al. 2022). Over the globe, cheese holds a prominent position as a staple dairy food. Effective advancement of lentil milk–based cheese would carry a broad monetary advantage to the food industry. A fascinating transformation occurs in cheese analogs as nondairy fats replace their animal counterparts. These innovative creations are tailored to meet the specific demands of cheese-like products while forgoing dairy ingredients. Nondairy cheese alternatives are produced using techniques similar to processed dairy cheese (Craig, Mangels, and Brothers 2022). Consumers have many reasons related to health concerns, such as lactose intolerance or a milk allergy, for choosing plant-based cheese alternatives that inspire them to consume new products (Aydar, Tutuncu, and Ozcelik 2020). This study is aimed at formulating lentil milk–based soft cheese (LBC) using various types of lentil-based milk. This study can potentially expand the dairy industry by producing functional dairy items.

2 | Materials and Methods

2.1 | Sample and Material Collection

All LBC samples were made with locally sourced lentils (black, green, and red gram), salt, black pepper, and dairy yeast. Ninety-five percent sulfuric acid, sodium hydroxide, hydrochloric acid, hexane, ethanol, and methanol was procured from Sigma-Aldrich and used as such. All the chemicals used for quantitative and qualitative analysis of LBC samples were analytical grade.

2.2 | Formulation of LBC

All LBC samples were prepared following the method reported by Moradi, Ziarati, and Sawicka (2021) with slight modifications. Each selected lentil used for the preparation of LBC, including 300 g of green gram (S_1), black gram (S_3), and red gram (S_2), was soaked in potable water for 12 h before being blended separately until a completely smooth mixture was achieved, then strained through a muslin cloth. Then, each collected lentil mixture was heated in a saucepan over a low flame (< 80°C) with continuous stirring until a thick consistency was achieved. Subsequently, about 6 g of spices (salt and black pepper) and 8 g of yeast (*Saccharomyces cerevisiae*) were added, followed by 1 min heating and molding. After 24 h of refrigeration, each cooled cheese curd was transferred to airtight containers for further analysis. All prepared LBC samples were investigated in three batches over 15 days at 3-day intervals. Table 1 presents the ratio of all ingredients used in the formulation of the LBC samples.

TABLE 1 | Ratios of all ingredients used in formulation of lentil-based soft cheeses.

Ingredients	Grams	Ratio
Black gram, red gram, green gram	300	50
Water	200	33
Salt	6	1
Black pepper	6	1
Rossmoor dairy yeast	18	3

2.3 | Physicochemical Analysis of LBC

The proximate analysis, including moisture (%), crude fat (%), crude protein (%), and total ash (%) of LBC samples, was conducted using official AOAC methods. Moisture (AOAC 925.09), crude fat (AOAC 920.39), crude protein (AOAC 979.09), and total ash (AOAC 923.03) were used. The moisture content of LBC samples at 70°C was measured using a high-quality stainless steel hot air oven by UF450TS, Memmert (Surber et al. 2021).

Crude fiber content was determined according to AOAC Official Method 962.09. A Mettler Toledo pH meter with a standard line electrode was used to measure the pH of all LBC samples using the methods reported by Shori, Yong, and Baba (2022). For syneresis determination, 25 mL of each LBC sample was placed into the calibrated test tube after mixing and centrifuged for 7 min at 3394 rpm. The volume of isolated whey was measured and taken as milliliters per 100 g of cheese (Surber et al. 2021). Brookfield DVE viscometer was used to measure the viscosity of LBC samples by following the method reported by Amini et al. (2019).

2.4 | Texture Analysis of LBC

To determine the texture of all LBC samples, the texture analyzer (Imada, Toyohashi, Japan), which can weigh up to 7 g of samples, was used. Each sample was collected from a depth of 2 cm by maintaining the dimension (2×2 cm) from each LBC block and stored at 4°C. A conical probe with a 20 mm diameter was used to penetrate each sample at a speed of 5 mm/s to measure cheese hardness (N). The shear force test was carried out with a cleaver probe of 20 mm diameter at a speed of 2 mm/s (Shan et al. 2020).

2.5 | Color Profile Determination of LBC

The colorimeter analysis of LBC samples was carried out on the 1st, 4th, 7th, 11th, and 15th day of storage at 4°C by using a digital colorimeter (Chroma Meter, Konica Minolta, Japan) following the method reported by Minz and Saini (2021). CIElab color parameters were measured to obtain the lightness (L), redness (+a), greenness (−a), yellowness (+b), and blueness (−b) in samples. The total color difference (ΔE) was measured in each LBC sample and calculated using Equation (1), as reported by Fernandes et al. (2020).

$$\Delta E^{*} = \sqrt{(\Delta L^{*})^{2} + (\Delta a^{*})^{2} + (\Delta b^{*})^{2}} \tag{1}$$

2.6 | Sensory Evaluation of LBC

The selected laboratory panel and random consumer panel evaluated all LBC samples using a 9-point hedonic scale. The parameters on a scale of 1–9 ranged from not noticeable to very strong, depending on taste, flavor, color, texture, and appearance. All LBC samples were presented to panels in triplicate, as reported by Moss et al. (2023). The samples were formulated thrice and subjected to sensory evaluation in the same manner for the storage study (Pointke et al. 2022).

2.7 | Microbial Analysis of LBC

The spread plate technique was used to quantify the microbial load as total plate count (TPC). All the prepared LBC samples were cultured on a nutrient agar medium and incubated at 35°C for 24 h. Finally, microbial counting was performed by using the colony counter (Weragama et al. 2021).

2.8 | Statistical Analysis

All the physicochemical and textural analyses were performed in triplicate, and data was statistically analyzed using Statistix 8.1 software. Two-way ANOVA determined the difference between means of all attributes measured during storage. One-way ANOVA was used for proximate, texture, colorimeter, and sensory analysis to determine the significant differences ($p < 0.05$) between means. Tukey's test was used to compare the means of the samples.

3 | Results

3.1 | Physicochemical Analysis of LBC Samples

Table 2 presents the comprehensive results of the proximate analysis of all LBC samples. The proximate analysis of LBC showed that the samples prepared using S_1 showed the highest mean ash content values (0.93%). The minimum moisture content (72.44%) was measured by the S_2 sample. The highest crude fat of about 0.96% was obtained in the LBC sample prepared using S_3, while S_1 and S_2 presented similar values (0.93%). The current study reported the pH values for all the LBC samples within the range of 5.80–6.72. For this study, the maximum mean value of the crude fiber was 1.08% in the S_1 LBC sample, while the minimum value was reported as 0.59% in S_3. Nitrogen-free extract (NFE) for all the LBC samples varied from 19.87% to 10.77%. The means for crude protein were 3.16%–6.74%. In terms of energy, S_3 (90.53 kcal) was the highest in all the means as compared to S_1 (78.47 kcal) and S_2 (86.60 kcal). All the parameters varied significantly ($p < 0.00$) among three different LBC samples, except crude fat ($p > 0.50$), which was nonsignificant in all three samples.

3.2 | Syneresis of LBC Samples

The detailed results of the syneresis of LBC samples during storage are presented in Table 3. According to the results, the difference between time, samples, and interactive effect was highly significant in syneresis ($p < 0.00$). Mean values from Day 1 to Day 15, from 0 to 1.17 mL, have been inclined to increase continuously. For syneresis, S_1, S_2, and S_3 have presented the increased trends with the means from Day 1 to Day 15 from 0 to 1.01 mL, 0 to 1.01 mL, and 0 to 1.51 mL, respectively.

3.3 | Viscosity of LBC Samples

The viscosity values for all the LBC samples are shown in Table 4. Viscosity results showed a significant interaction ($p < 0.05$) with time among all samples. The highest mean for viscosity was

TABLE 2 | Results showing the proximate analysis of lentil milk–based soft cheese.

Parameters	S_1	S_2	S_3
Moisture (%)	79.58 ± 0.36a	72.44 ± 0.47b	79.52 ± 0.31a
Ash (%)	0.93 ± 0.00b	0.88 ± 0.00a	0.86 ± 0.03b
Protein (%)	6.74 ± 0.22a	5.13 ± 0.18b	3.16 ± 0.11c
Fat (%)	0.93 ± 0.01a	0.93 ± 0.02a	0.96 ± 0.04a
Fiber (%)	1.08 ± 0.00a	0.66 ± 0.00b	0.59 ± 0.00c
NFE (%)	10.77 ± 0.51c	19.87 ± 0.30a	10.77 ± 0.20b
Energy (kcal)	78.47 ± 1.47c	86.60 ± 1.25b	90.53 ± 1.09a

Note: Different notations (a–c) show significant differences in the proximate composition at a 95% probability level.
Abbreviations: S_1 = green gram, S_2 = red gram, S_3 = black gram.

TABLE 3 | The physicochemical properties of lentil milk–based soft cheese samples.

Parameters	Storage time	S_1	S_2	S_3
Microbial count (CFU)	Day 1	7.89 ± 1.00c	2.88 ± 150j	1.39 ± 1.46n
	Day 4	6.19 ± 1.40f	2.29 ± 1.32k	1.09 ± 1.62o
	Day 7	5.58 ± 1.27g	2.19 ± 1.32l	9.28 ± 1.24b
	Day 11	5.28 ± 1.29h	2.09 ± 1.96m	7.48 ± 1.65d
	Day 15	4.98 ± 1.27i	9.68 ± 3.96a	7.09 ± 1.65e
pH	Day 1	6.72 ± 0.00a	6.20 ± 0.00e	6.51 ± 0.01b
	Day 4	6.41 ± 0.00c	5.94 ± 0.01h	6.41 ± 0.01c
	Day 7	6.15 ± 0.00f	5.87 ± 0.01i	6.32 ± 0.00d
	Day 11	5.92 ± 0.01h	6.01 ± 0.02g	5.99 ± 0.01g
	Day 15	5.86 ± 0.00i	6.51 ± 0.00b	5.80 ± 0.01j
Syneresis (mL)	Day 1	0.00 ± 0.00c	0.00 ± 0.00c	0.00 ± 0.00c
	Day 4	0.03 ± 0.00b	0.03 ± 0.00b	0.04 ± 0.00b
	Day 7	0.09 ± 0.00b	0.09 ± 0.00b	0.08 ± 0.00b
	Day 11	0.50 ± 0.00ab	0.50 ± 0.00ab	0.62 ± 0.00ab
	Day 15	1.01 ± 0.01a	1.01 ± 0.01a	1.51 ± 0.01a

Note: Different notations (a–o) show significant differences in the physiochemical properties at a 95% probability level.
Abbreviations: S_1 = green gram, S_2 = red gram, S_3 = black gram.

recorded on Day 15 (59.3 mPa·s), and the lowest was recorded on Day 1 (54.0 mPa·s). According to the type of cheese, the viscosity means also varied, with the highest mean in S_2 (58.03 mPa·s) followed by S_3 (57.36 mPa·s) and S_1 (54.72 mPa·s). Overall, the results showed an increased interactive effect of S_1, S_2, and S_3 on viscosity. For viscosity, the highest value was observed in S_3 at Day 15 (61.53 mPa·s), followed by S_2 (58.93 mPa·s) and S_1 (57.46 mPa·s).

3.4 | Texture Analysis of LBC

Cheese hardness represents the measurement of the force (newton) required to reach the first compression peak of deformation that can be affected by moisture content. Texture analysis (hardness) results showed a significant interaction ($p < 0.05$) among all samples. Texture hardness was further investigated using the shear and puncture force test on different storage days. All the results of the texture analysis of LBC cheese samples are shown in Table 4. Among all samples, S_3 had the lowest puncture value (2.34×10^3 N), followed by S_2 (4.03×10^3 N) and S_1 (5.72×10^3 N) on Day 1. The puncture force values for S_2 and S_3 samples were low on Day 1, indicating a softer texture due to moisture retention, which acts as a plasticizer, resulting in a more fluid-like behavior and a softer cheese texture. However, on Day 15, S_2 and S_3 experienced higher puncture force values and presented an overall harder texture ($p < 0.05$). This implied that these samples matured and hardened over time due to moisture loss. S_1 showed a decreasing trend from Day 1 to Day 15. The shear measurements also presented increased force values in S_3 (3.39×10^3–5.84×10^3 N). From Day 1 to Day 11, S_2 exhibited a decreasing trend toward hardness. However, on Day 15, it showed an upward trend, indicating that changes in moisture content and water activity during the early stages of maturation could influence the cheese's texture and shear force, making it softer. The shear hardness of S_1 continuously decreased as Day 1 had the highest mean value (1.38×10^4 N), and Day 15 showed the lowest mean value (1.06×10^4 N).

3.5 | Colorimetric Analysis of LBC

The results of the colorimetric analysis (Table 5) for this study reported that the L value of S_1 (39.61–44.85), S_2 (44.85–53.64), and S_3 (41.64–44.03) increased from Day 1 to Day 15, showing that the color of lentil milk-based cheese lightened (Figure 1) with time. Regarding the a value representing the green-to-red hues, all the LBC samples showed an increasing trend from Day 1 to Day 7 and after Day 7, a decreasing trend was observed till Day 15. Overall, the color profile indicated a slight shift toward the red spectrum in the LBC samples, with the highest value observed in S_3 (3.10).

On the contrary, considering the "b" values, representing the blue to the yellow color, the highest b value was observed in S_1 (18.46). However, the overall color profile showed a significant difference ($p < 0.05$).

3.6 | Microbial Count of LBC

ANOVA and mean regarding the microbial content of all LBC samples during the storage period is shown in Table 3. The

TABLE 4 | The texture properties of lentil milk–based soft cheese.

Days	S_1			S_2			S_3		
	Fracturability hardness (N)	Shear hardness (N)	Viscosity (mPa·s)	Fracturability hardness (N)	Shear hardness (N)	Viscosity (mPa·s)	Fracturability hardness (N)	Shear hardness (N)	Viscosity (mPa·s)
1	$5.72\times10\pm0.32^{a}$	$1.38\times10\pm0.04^{a}$	53.80 ± 0.65^{h}	$4.03\times10\pm0.18^{b}$	$8.16\times10\pm0.66^{a}$	52.00 ± 0.30^{i}	$2.34\times10\pm0.37^{b}$	$3.39\times10\pm0.49^{c}$	56.46 ± 0.35^{def}
4	$5.86\times10\pm0.31^{a}$	$1.32\times10\pm0.07^{ab}$	55.40 ± 0.50^{fg}	$4.23\times10\pm0.26^{ab}$	$6.71\times10\pm1.03^{ab}$	53.43 ± 0.45^{h}	$2.30\times10\pm0.21^{b}$	$3.79\times10\pm0.25^{bc}$	57.83 ± 0.45^{cd}
7	$5.84\times10\pm0.49^{a}$	$1.21\times10\pm0.10^{abc}$	56.46 ± 0.20^{def}	$4.56\times10\pm0.18^{ab}$	$5.41\times10\pm1.15^{ab}$	54.70 ± 0.62^{gh}	$2.23\times10\pm0^{b}$	$4.06\times10\pm0.65^{abc}$	58.96 ± 0.30^{bc}
11	$5.36\times10\pm0.23^{a}$	$1.15\times10\pm0.09^{bc}$	57.30 ± 0.36^{de}	$4.93\times10\pm0.35^{ab}$	$4.93\times10\pm1.43^{b}$	56.03 ± 0.30^{efg}	$2.79\times10\pm0.13^{ab}$	$5.52\times10\pm0.74^{ab}$	60.30 ± 0.40^{ab}
15	$4.99\times10\pm0.49^{a}$	$1.06\times10\pm0.01^{a}$	58.93 ± 0.75^{bc}	$5.09\times10\pm0.64^{a}$	$7.95\times10\pm1.68^{a}$	57.46 ± 0.55^{d}	$2.98\times10\pm0.18^{a}$	$5.84\times10\pm0.97^{a}$	61.53 ± 0.55^{a}
p value	0.07	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00

Note: Different notations show significant differences in the texture properties at a 95% probability level.
Abbreviations: S_1 = green gram, S_2 = red gram, S_3 = black gram.

TABLE 5 | The color properties of lentil milk–based soft cheese.

Days	S_1			S_2			S_3		
	L	a	b	L	a	b	L	a	b
1	39.61 ± 0.96a	0.13 ± 0.02a	14.88 ± 0.44c	40.40 ± 2.71c	7.97 ± 0.42a	15.01 ± 0.91c	41.64 ± 2.96b	2.99 ± 0.16a	11.43 ± 0.51b
4	41.08 ± 1.80a	0.17 ± 0.04a	16.04 ± 0.44bc	47.63 ± 6.51bc	8.61 ± 0.09a	17.18 ± 0.25b	44.98 ± 1.44ab	3.14 ± 0.08a	12.15 ± 0.27ab
7	43.63 ± 3.98a	0.20 ± 0.03a	16.93 ± 1.08ab	56.92 ± 2.93a	9.12 ± 0.35a	19.89 ± 1.05a	49.65 ± 2.76a	3.36 ± 0.17a	12.74 ± 0.63a
11	42.68 ± 1.27a	0.12 ± 0.06a	17.48 ± 0.63ab	54.60 ± 0.53ab	8.37 ± 0.48a	18.57 ± 0.14ab	45.92 ± 2.99ab	3.22 ± 0.16a	11.81 ± 0.37ab
15	44.85 ± 1.20a	0.063 ± 0.11a	18.46 ± 0.69a	53.64 ± 0.89ab	7.76 ± 0.13a	17.77 ± 0.53b	44.03 ± 1.37ab	3.10 ± 0.35a	11.39 ± 0.53b
p value	0.80	0.12	0.00	0.00	0.00	0.00	0.02	0.27	0.03

Note: Different notations show significant differences in the color properties at a 95% probability level.
Abbreviations: S_1 = green gram, S_2 = red gram, S_3 = black gram.

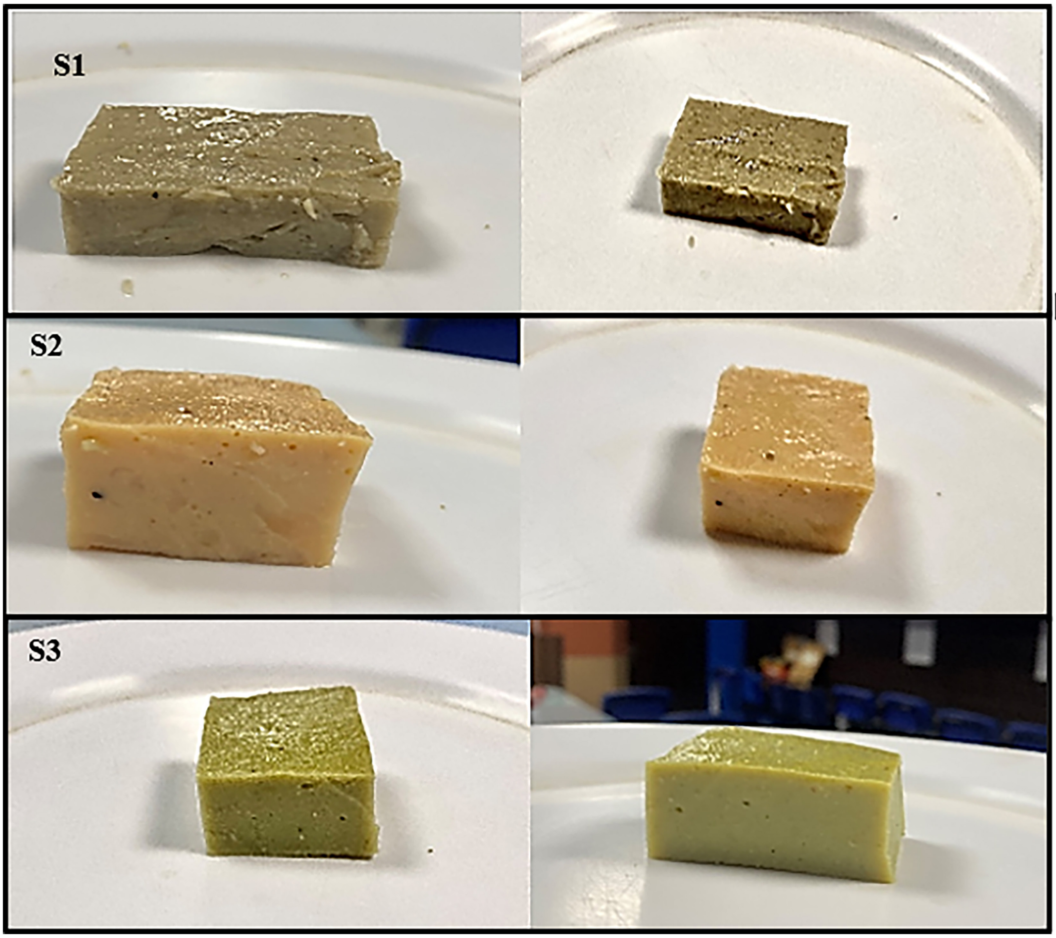

FIGURE 1 | Pictorial representation showing the results for the colorimeter of freshly prepared lentil milk–based soft cheese samples. S_1 = green gram; S_2 = red gram; S_3 = black gram.

results showed a significant interaction between time and treatment (p = 0.00). Day 15 showed the mean value (7.25 CFU/mL), and Day 4 showed the lowest mean value (3.19 CFU/mL). All three types of cheese also varied in their microbial content, as S_1 had the highest mean value (5.98 CFU/mL), followed by S_3 (5.26 CFU/mL) and S_2 (3.82 CFU/mL), respectively. The microbial count of S_1 continuously decreased; Day 1 had the highest mean value (7.89 CFU/mL), and Day 15 had the lowest mean value (4.98 CFU/mL). In S_2, the microbial content showed variation, as on Day 1, the microbial content was 2.88 CFU/mL, and on Days 4, 7, and 11, it showed a decreasing trend, and on Day 15, it increased again (9.68 CFU/mL). Furthermore, S_3 also showed a difference from Day 1 to Day 7, as the microbial content increased from 1.39 to 9.28 CFU/mL. Pearson's correlation (Tables S1–3) results also showed a significant correlation between the microbial content and pH ($p < 0.05$). Similarly, syneresis and viscosity also showed a significant correlation ($p < 0.05$).

3.7 | Sensory Evaluation of LBC

All LBC samples were presented to the trained panelists for sensory evaluation using a 9-point hedonic scale. The graphical representation of the sensory evaluation of all LBCs is presented in Figure 2. Based on the bitterness, S_3 achieved the highest mean among all samples, while S_1 was the least liked by the panel. This bitterness overshadows the desirable flavor in the S_3 formulation. An organoleptic mean of color for LBC samples exhibited the highest mean value in S_3 (7.42), followed by S_2 (4.14) and S_1 (3.85). On the other hand, dull color demonstrated the highest mean value in S_2 (7.85) and the lowest mean value in S_1 (3.71).

The result for the difference in saltiness showed that LBC prepared using green gram (7.00) exhibited the highest mean score in saltiness and less in S_2 (3.85). Parameter granularity has the highest mean in S_3 (6.00), followed by S_2 (4.14) and S_1 (1.57). Adhesiveness has been shown more in S_1 (7.00) and less in S_3 (3.85). For roughness, the highest mean value was obtained by S_1 (4.57) and the lowest mean value in S_3 (1.57).

Based on the taste, the highest mean value, metallic and pungency, was observed in S_2, and the lowest mean value was shown in the S_1 sample. The same mean values in firmness and surface moisture (6.42) were observed. However, a different mean score in softness was observed (6.57) in S_1 samples. S_2 and S_3 had the highest mean firmness of 8.14 and 6.28, respectively, followed by softness of 7.28 and 5.57 and surface moisture of 6.00 and 5.42.

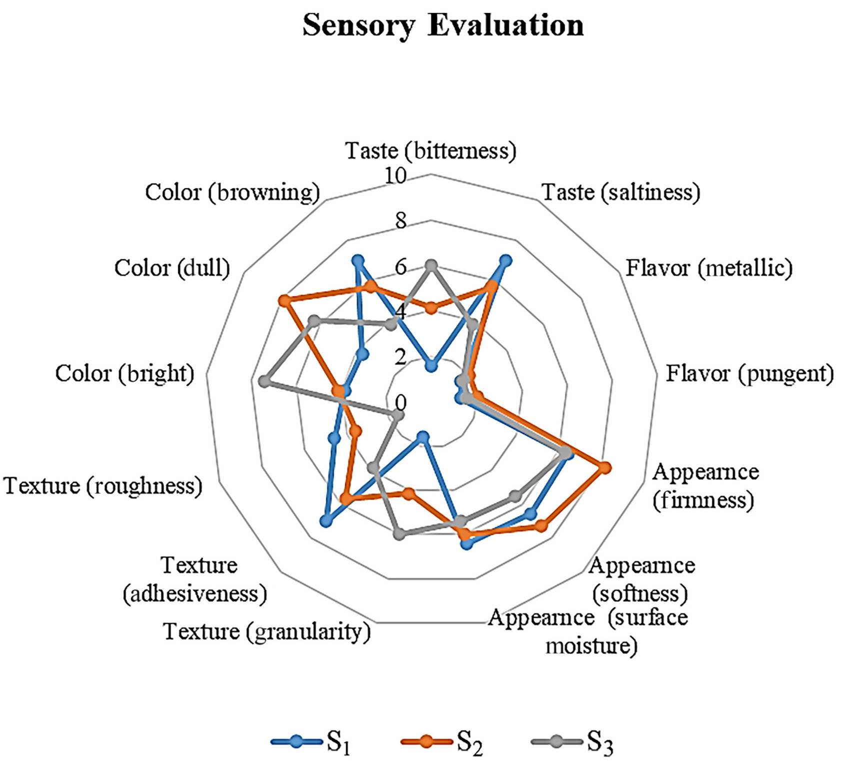

FIGURE 2 | Graphical representation showing the results for the sensory evaluation of lentil milk–based soft cheese samples. S_1 = green gram; S_2 = red gram; S_3 = black gram.

4 | Discussion

This study evaluates the potential of lentil milk as a suitable ingredient for designing plant-based soft cheeses. The lentil milk offers a nutritious option for consumers with dietary preferences or restrictions. The possible reasons for the change in pH could be due to the aging and ripening of plant milk–based cheese, enzymes present in the lentil milk or incorporated during processing that are further metabolized by microbes, generating organic acids that contribute to pH reduction (Mohsin et al. 2024). Also, acidic byproducts may be produced when yeast enzymes break down proteins into peptides and amino acids so that the cheese's pH becomes more acidic as time passes (Jach et al. 2022).

Regarding proximate analysis, the results align with the previous study that reported soy-based vegan cheese analog contained 52.8% moisture, 2.2% ash, 0.2% crude fiber, 25.2% NFE, 19.2% crude fat, and 0% protein (Ferawati et al. 2021). All the parameters varied significantly ($p < 0.00$) among three different lentil-based cheeses, except crude fat ($p > 0.50$), which was nonsignificant in all three samples.

For syneresis, S_1, S_2, and S_3 showed increased trends with the means from Day 1 to Day 15 from 0.00 to 1.01 mL, 0.00 to 1.01 mL, and 0.00 to 1.51 mL, respectively. A correspondence study also showed a significant relationship with this study, indicating increased syneresis values as the days passed (Ferawati et al. 2021). The possible reason could be the interaction of proteins to make a gel, forming an intricate network and affecting water retention (Rinaldoni et al. 2014). The cheese's acidity may also impact protein interactions. Low pH can lead to various protein aggregates, promoting syneresis (McClements and Grossmann 2022).

For viscosity, the highest value was observed in S_3 at Day 15 (61.53 mPa·s), followed by S_2 (58.93 mPa·s) and S_1 (57.46 mPa·s). This study's results also showed strong agreement with those of Uzuner et al. (2016), who reported that the viscosity of plant-based cheese samples was increased during storage due to the tightening of the protein gel matrix.

The microbial growth results also agree with those of Paul et al. (2020), which showed an increasing trend in microbial growth during storage. The possible reason could be the rapid increase in storage temperature. Another study was conducted by Bristone et al. (2018) to evaluate the microbial quality of soybean cheese. The result depicted an increase in the high microbial load over time. A similar study observed a significant decrease ($p < 0.05$) in the textural properties of green gram paneer. The lower hardness of hybrid paneer was developed by partially replacing cow milk with mung bean protein, possibly due to increased moisture content (Tojan 2021).

The correlation analysis between pH and microbial content suggested that with a decrease in pH, the microbial load also reduced, indicating that microorganisms are vulnerable to acidic environments. Therefore, reduced microbial content can result from the acidic environment that harms microbial cell membranes, denatures proteins, and disrupts enzyme function. The correlation between microbial and pH showed a similar trend (Bhavaniramya et al. 2019). The possible reason for the correlation between syneresis and viscosity is the gel structure of cheese degrading as the matrix becomes unstable and releases more water. This causes the gel to weaken to release water and increase in viscosity. The results also agreed with Mattice and Marangoni (2020), who showed the relevant trend.

A lighter cheese color might be caused by decreasing or removing these colored compounds due to protein denaturation (Sharan et al. 2021), as shown in Figure 1. Reddish-brown pigments may be formed due to protein denaturation in conjunction with additional Maillard reactions, which might contribute to a shift toward the red spectrum (Zhang et al. 2023). The possible reason is that the yellow hues in the LBC samples were caused by carotenoids, such as lutein, zeaxanthin, and β-carotene (Chudy et al. 2020). A similar study in correspondence with the current research reported that cheese analogs made from roasted pulse flours tended to have higher redness but lower lightness and yellowness levels than cheese analogs made from boiled pulse flours (Ferawati et al. 2021).

The bitterness in the LBC sample prepared with black gram was due to the presence of husk intact with the pulse containing high tannins (Hadedy et al. 2017). A study also reported that cheese color is influenced by several factors, including the type of pulse used, fat content, cheese packaging, and storage conditions (Bekele et al. 2019). Increased surface moisture in cheese can enhance the perception of saltiness because moisture helps distribute salt more evenly across the taste bud (Hu et al. 2024). The duration and condition of aging can affect the development of texture. Longer aging periods often produce a more crystalline or granular texture (Nájera et al. 2021). More metallic and pungency in LBC samples were prepared using red gram due to the storage condition that can impact its flavor profile (Ali, Nada, and Al-Moghazy 2021). As reported in a study, firmness is reciprocal to moisture content, whereas softness is directly linked with moisture content (Al-Saedi et al. 2021).

5 | Conclusion

This research investigated the physicochemical and textural properties of LBC, which unveiled valuable insights into innovative dairy alternatives. This study conducted proximate analysis on all three LBC samples, revealing that green gram cheese was more nutritionally beneficial than red and black gram cheeses. This study showed that the highest crude fat (0.96%) was obtained in LBC prepared using black gram (S_3). Green gram (S_1) presented the highest crude protein of about 6.74%, while the lowest was about 3.1%, obtained in LBC with black gram (S_3). The results of texture analysis showed an improved texture in overall LBC cheese as the highest value was observed in S_3 at Day 15 (61.53 mPa·s), followed by S_2 (58.93 mPa·s) and S_1 (57.46 mPa·s). S_1, S_2, and S_3 showed increased trends for syneresis from Day 1 to Day 15. According to the colorimeter analysis, the S_2 sample showed an increasing trend in all colorimetric attributes. The organoleptic properties indicated that S_1 showed the highest scores, specifically in appearance, texture, and color. It can be concluded that the findings underscored the potential of lentil milk as a suitable ingredient for soft cheese production, offering a nutritious and appealing option for consumers with dietary preferences or restrictions. Further research and development could lead to novel, health-conscious dairy products, aligning with the growing demand for plant-based alternatives in the modern food industry.

Author Contributions

Hafsa Naeem: conceptualization, data curation, formal analysis, investigation, methodology, visualization, writing – original draft. **Aqsa Akhtar:** formal analysis, investigation, methodology, validation, visualization, writing – original draft. **Nadia Akram:** conceptualization, formal analysis, supervision, validation, writing – original draft, writing – review and editing. **Hafiz Ansar Rasul Suleria:** funding acquisition, resources, writing – original draft, writing – review and editing. **Nauman Khalid:** conceptualization, methodology, validation, visualization, writing – original draft, writing – review and editing.

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Ethics Statement

The authors have nothing to report.

Consent

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data and corresponding information can be requested from the corresponding authors.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.