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RESEARCH ARTICLE
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Incorporation of Cow's and Goat's Milk and Its Effect on The Texture Profile and Quality of Cheddar Cheese

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ABSTRACT

This study aimed to analyze the effect of incorporating cow's milk and goat's milk on the physicochemical characteristics, texture, amino acid and fatty acid profiles, and functional activity of Cheddar cheese. Cheeses were produced using four treatments, namely 100% cow's milk, 100% goat's milk, 70% cow's milk:30% goat's milk, and 30% cow's milk:70% goat's milk. Analyses were conducted for pH, moisture, protein, fat, ash, texture profile, color, antioxidant activity (DPPH), microbiological quality, as well as amino acid and fatty acid profiles using FTIR, HPLC, and GC-FID methods. Sensory evaluation involved 25 semi-trained panelists using a 5-point hedonic scale, and data were analyzed by one-way ANOVA followed by Duncan's test ($P<0.05$). The results showed that the 30% cow's milk:70% goat's milk treatment produced cheese with lower pH, higher protein content, and dominant amino acids (glutamate, proline, leucine). The highest antioxidant activity was observed in cheeses with higher proportions of cow's milk, while goat's milk contributed to higher levels of medium-chain fatty acids. Sensory evaluation revealed that all treatments were accepted by panelists within the "like" to "strongly like" category. This study provides practical implications for the development of functional Cheddar cheese based on cow–goat milk blends and represents an original contribution to the scientific basis of goat milk utilization in the dairy industry under tropical conditions.

Keywords: Cheddar cheese, Cow milk, Goat milk, Antioxidant activity, Texture profile.

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INTRODUCTION

The strengthening of downstream technology for livestock products is an important effort to increase the added value of animal-derived commodities, particularly the processing of milk into cheese. In general, cheese is defined as a homogeneous mixture of several ingredients with milk as the primary raw material (Gulzar et al., 2020). One of the main limitations of processed cheese is its weak functional value. Therefore, the incorporation of additional ingredients that enhance the activity of functional components in cheese has become increasingly important (Shaukat et al., 2022). Several studies have addressed this issue, including the addition of plant powders (El-Loly et al., 2022), fruits (Abbas et al., 2021), purple sweet potato and Moringa leaf extract (Miwada et al., 2019; Miwada et al., 2023), as well as oat flour and vegetable oils (Hamdy et al., 2021).

Nevertheless, research on the combination of cow's milk and goat's milk in Cheddar cheese production as a strategy to improve both functional and organoleptic properties remains limited, particularly in tropical contexts and in determining optimal ratios. Goat's milk has several physiological advantages, such as easier digestibility, hypoallergenic properties, and a higher content of medium-chain fatty acids, although its drawback lies in the characteristic "goaty" flavor that is less favored by some consumers (Queiroga et al., 2013; Bruzantin et al., 2016; Feng et al., 2019). Goat's milk has a protein structure that is

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more easily digested than cow's milk, as shown in goat's milk curd products, which have a softer and more open texture than cow's milk curd. Furthermore, goat's milk contains smaller and more dispersed fat globules, increasing the efficiency of digestive enzymes in the human body (Mishra et al., 2025). Although goat's milk has superior nutritional qualities, its taste is less popular with customers. One way to balance the flavour of goat's milk cheese is to mix it with cow's milk to reduce the sharp taste and create a firm cheese (Fiutak-Filipczak et al., 2021). Goat's milk has a lower content of αs1-casein than cow's milk, the main protein that often causes cow's milk allergies. This reduced αs1-casein content makes goat's milk more tolerable for individuals with cow's milk allergies (ALKaisy et al., 2023).The combination of cow's and goat's milk is expected to complement each other's strengths and weaknesses; however, scientific data evaluating the texture, antioxidant activity, microbiological quality, and amino acid and fatty acid profiles of Cheddar cheese produced from such incorporation are still scarce and not standardized. This study provides novelty in the formulation of Cheddar cheese based on proportional blends of cow's and goat's milk, with an evaluation not only of physicochemical quality but also of functional characteristics such as antioxidant activity and antibacterial activity, which have rarely been analyzed simultaneously in previous studies. In addition, the integrative approach using FTIR, HPLC, and GC-FID strengthens the depth of chemical and functional analysis. The hypothesis proposed is that the incorporation of goat's milk in dominant proportions (≥70%) into cow's milk can improve the functional characteristics of Cheddar cheese without significantly reducing its sensory acceptance and textural properties compared with cheese made from pure cow's or goat's milk.

MATERIALS & METHODS

Materials

The raw materials consisted of fresh cow's milk, fresh goat's milk, and blends of both in different proportions as follows:A=100% cow's milk; B=100% goat's milk; C=70% cow's milk : 30% goat's milk, and D=30% cow's milk: 70% goat's milk.

The starter culture used was a mixture of *Lactococcus lactis subsp. lactis*, *L. lactis subsp. cremoris*, and *Lactococcus lactis subsp. diacetylactis* at 2% v/v. The lactic acid bacteria used in this study are commonly used for fermented cheese products, which play an important role in developing flavor, texture, and consistency (Kadir et al., 2025).The coagulant enzyme used was commercial liquid rennet (*Chr. Hansen®, strength 1:10,000*) at 0.2 mL/L of milk. Salt (NaCl) at 5% of the curd weight was applied during ripening.

Cheddar Cheese Production

Cheese production followed the method of Miwada et al. (2023) with modifications:

The raw materials for making cheese are fresh milk that meets SNI 3141:2024 standards, namely fresh cow's milk containing 3.06% protein and 3.57% fat, while fresh goat's milk contains 3.69% protein and 6.75% fat. Fresh milk was pasteurized at 70°C for 30 minutes, and then the milk was cooled to 37°C, followed by inoculation with starter culture and rennet. The rennet used is 2 grams for 40 liters of milk. The mixture was incubated at 37°C for 2 hours until coagulation. Whey was drained, the curd was molded, salted at 5%, and ripened. Ripening was carried out for 1 month and 1 week at 10°C and 85% RH. This is faster because the cheese produced is smaller than the typical cheddar cheese. The salting method is carried out using mineral water and salt with a salting time of 2 hours.

Experimental Design

A completely randomized design (CRD) was applied with four treatments (A–D) and three independent biological replicates. Each parameter was analyzed in triplicate technical replicates (n=3). Data were presented as mean ± standard deviation and analyzed using one-way ANOVA followed by Duncan's test ($P<0.05$) with SPSS version 25.

FTIR Functional Group Analysis

FTIR spectra were used to detect molecular functional group changes. The water content of the cheese samples was reduced by weighing 1 gram of cheese, then ground they were dried using an oven at 60ºC for 6 hours. FTIR analysis was performed using the Shimadzu IRSpirit with the ATR-S accessory. The smooth, dried cheese sample was then placed on the ATR crystal. The instrument was turned on, and LabSolutions IR software was used to configure the project and measurement method. Background measurements were then performed before measuring the sample. The wavelength range used was 4000-500 cm^{-1}. The spectral data obtained were then processed with baseline correction and normalisation to ensure the quality of the spectrum. Component identification was performed by comparing the sample spectrum with a standard library. After the analysis was completed, the results were stored and reported. Spectra interpretation followed the method of Hashim et al. (2010) to identify functional vibrations such as methyl, methylene, ester, carbonyl, and aromatic groups.

Physicochemical Analysis

- **pH:** Measured using a digital pH meter.
- **Moisture:** Determined by oven drying at 105°C for 4 hours (AOAC, 2005).
- **Protein:** Determined using the Kjeldahl method (AOAC, 2005).
- **Fat:** Determined using the Gerber method.
- **Ash:** Determined by incineration in a muffle furnace (AOAC, 2005).

Antioxidant activity (DPPH)

Antioxidant activity was determined by the DPPH method following Lee and Bae (2018). Results were expressed as mg GAE/L.

Microbiological Analysis

- **Total Plate Count (TPC):** Conducted using nutrient

agar (NA). The dilutions used were 10^{-3}, 10^{-4}, and 10^{-5} using the pour plate technique with an inverted petri dish for 24 hours at 37°C. The growing colonies are counted using a colony counter.

- **Antimicrobial activity:** The cheese was extracted with 80% ethanol and then taken at concentrations of 25 and 50 mg/mL. Inhibition against *Staphylococcus aureus* and *E. coli* was assessed using the Kirby–Bauer method with paper discs, and inhibition zones were observed after 24 h incubation. The inhibition zone is measured with a vernier caliper and is measured in mm (Rahmadi et al., 2025).The diffusion control used was ethanol and the positive control used Penicillin for *Staphylococcus aureus* and Ampicillin for *E. coli*.

Sensory Evaluation (Hedonic Test)

A hedonic test was conducted to evaluate consumer acceptance of the cheeses. A total of 25 semi-trained panelists participated. Inclusion criteria included: (1) age 18–45 years, (2) no allergies to dairy products, (3) regular consumption of dairy products at least twice per week, and (4) informed consent.

The hedonic scale ranged from 1 to 5 (1=strongly dislike, 5=strongly like) for color, aroma, texture, taste, and overall acceptance (Susilo et al., 2024). The scale was validated by internal consistency testing (Cronbach's alpha > 0.70). Each sample was evaluated in triplicate under blinding conditions using randomized three-digit codes. Sample presentation order was randomized to avoid order bias. Data were analyzed using one-way ANOVA, and significant differences ($P<0.05$) were further examined by Duncan's test.

Texture Profile Analysis

Texture was measured using a TA-XT2 Texture Analyzer under the following conditions:Pre-test speed: 2.0 mm/s, Post-test speed: 5.0 mm/s, Maximum load: 2 kg, Trigger distance: 8 mm, and Force: 5 g. Parameters included hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness, and resilience (Bozkurt & Bayram, 2006).

Color Analysis

Color was measured using a chromameter as described by Yoo et al. (2019), yielding: L* (lightness), a* (redness–greenness) and b* (yellowness–blueness).

Amino Acid Profile

Protein was hydrolyzed with 6N HCl, separated using HPLC with sodium citrate buffer according to AOAC (2005), and quantified by comparison with standard chromatograms.

Fatty Acid Profile

Lipids were extracted with chloroform:methanol (2:1), converted into methyl esters, and analyzed using GC (Hewlett–Packard 6890 GC with FID detector) equipped with a Supercowaxtm column (30 m × 0.32 mm × 0.25 µm). The analysis followed Yang et al. (2009) with an initial column temperature of 180°C, increasing to 230°C.

Statistical Analysis

All data were analyzed quantitatively using descriptive and inferential statistics. Results were presented as mean±SD from three biological replicates and three technical replicates (n=9 per treatment). Differences among treatments were evaluated using one-way ANOVA with SPSS version 25. Significant effects ($P<0.05$) were further tested by Duncan's Multiple Range Test (DMRT).

For each significant result, the following were reported: F-value, p-value, Degrees of freedom (df) for treatment and error. For example:In antioxidant activity analysis, F=6.251, df=(3, 32), P=0.001.In texture profile (chewiness), F=4.712, df=(3, 32), P=0.005.Normality and homogeneity assumptions were verified using Shapiro–Wilk and Levene's tests. Significant differences in tables were denoted by superscript letters (a, b, c, etc.).

RESULTS AND DISCUSSION

Functional Group Analysis (FTIR)

The initial evaluation of cheese quality produced from cow–goat milk incorporation was carried out through functional group analysis using Fourier Transform Infrared Spectroscopy (FTIR). FTIR is a well-established method for detecting the vibrational states of chemical bonds in proteins and can be applied to study protein secondary structures (Yang et al., 2022). The FTIR spectra of the cheese samples revealed that none of the treatments exhibited identical spectral profiles, confirming compositional differences among samples. The functional groups identified in the spectra of the different treatments are presented in Table 1.

As illustrated in Fig. 1 and Table 1, the FTIR spectra indicated the presence of alkyl groups (methyl and methylene), esters, carbonyls, alkenes, and aromatic rings. These findings suggest that the analyzed compounds are likely to contain ester structures or aromatic compounds associated with alkyl or hydroxyl groups. The variation in functional groups across treatments reflects the influence of the milk blend ratios on the biochemical composition of the resulting cheese.In accordance with Subramanian's research, the wavelength region of 1800–900 cm^{-1} was detected in cheddar cheese, which is the region of organic acid groups, amino acids, and short-chain fatty acids that make a significant contribution to the taste of cheese (Subramanian et al., 2009).

The FTIR results obtained within the wavenumber range of 500–4000 cm^{-1} demonstrated distinct chemical variations in Cheddar cheeses produced from different cow–goat milk blends. Each absorption peak in the FTIR spectra corresponded to specific functional groups responsible for infrared absorption in the 500–4000 cm^{-1} region, and successfully differentiated cheeses made from blended milk (C and D) compared with those produced from pure cow's milk (A) or pure goat's milk (B). These findings confirm that FTIR is a suitable method for the authentication of milk fat composition (Windarsih et al., 2020).

Table 1: The functional groups in the cheese samples were identified based on the absorption peaks at specific wavenumbers observed in the FTIR spectra

Wavenumber region (cm^{-1})	Functional group and vibration
2918 dan 2854	C–H (asymmetric and symmetric stretching) in alkyl groups (CH_2 and CH_3), indicating the presence of methyl (–CH_3) and/or methylene (–CH_2–) groups.
1739	C=O (carbonyl stretching) in esters, aldehydes, or ketones, suggesting the possible presence of a carbonyl group (–C=O).
1625	C=C (stretching of carbon–carbon double bonds) in alkenes or aromatic compounds, typically observed in molecules containing C=C bonds.
1531	C=C (stretching in aromatic compounds) or amide (N–H bending), indicating the possible presence of aromatic rings or amide groups.
1459	C–H (bending of CH_2 or CH_3) in alkyl groups, generally representing bending vibrations of methyl or methylene groups.
1377	C–H (bending of CH_3) in alkyl groups, possibly indicating methyl substituents in the compound.
1237, 1168, 1101	C–O (stretching) in esters or alcohols, suggesting the possible presence of ester groups.
967, 721	C–H (bending) in alkyl groups, which may indicate methyl or methylene groups bound within specific structural arrangements.
721	C–H (bending) in aromatic compounds (benzene), often referred to as out-of-plane bending of C–H bonds in aromatic rings.

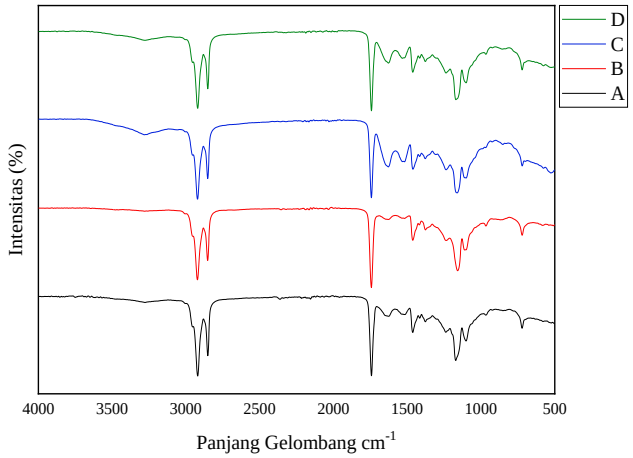

Fig. 1: FTIR spectra of Cheddar cheese produced from cow–goat milk incorporation.

Further observation of FTIR data indicated that suspensions of pure cow's milk (A), pure goat's milk (B), and their blends (C and D) exhibited normal dispersion. Although goat's milk is characterized by smaller fat globules, its incorporation with cow's milk did not negatively affect the suspension stability when compared with cheeses produced solely from cow's or goat's milk. This suggests that blending cow's and goat's milk can maintain the physicochemical integrity of the suspension in Cheddar cheese production.

Antioxidant Activity, Total Plate Count, and Antibacterial Activity

The antioxidant activity of Cheddar cheese produced from cow–goat milk incorporation is presented in Table 2. Significant differences ($P<0.05$) were observed among treatments. Cheeses produced from 100% cow's milk (treatment A) exhibited significantly higher antioxidant activity compared with those made from 100% goat's milk (treatment B). Interestingly, the 70:30 cow's-to-goat milk ratio (treatment C) yielded antioxidant activity comparable to treatment A, while the 30:70 ratio (treatment D) was statistically like treatment B.

These results highlight the influence of milk composition on the antioxidant potential of cheese. Cow's milk is richer in casein content, which contributes bioactive peptides with antioxidant activity, whereas goat's milk is characterized by higher levels of medium-chain fatty acids, polyunsaturated fatty acids, conjugated linoleic acid, calcium, phosphorus, magnesium, and copper (Ceballos et al., 2009). The interplay of these components explains the differential antioxidant activity observed in cheeses derived from pure or blended milk formulations.

The total plate count (TPC) of Cheddar cheese varied significantly ($P<0.05$) across treatments with different milk compositions. The lowest TPC value was observed in cheese produced from pure goat's milk (B). This finding supports the notion that goat's milk offers greater health potential due to its lower fat and lactose content, higher calcium and antioxidant levels, and inherent antibacterial properties (Mourad et al., 2014).The TPC count of cheddar cheese in the study was still within safe limits according to the International Dairy Federation (IDF). This is in line with research by Kunova et al. (2015) which stated that the total bacteria in cheese ranged from 9.54 x 10^3 to 1.71 x $10^5 CFUg^{-1}$, even though it was still considered safe after 5 days of storage at 4°C.

Regarding antibacterial activity, inhibition against *Staphylococcus aureus* was observed in cheeses produced from the 70:30 cow-to-goat milk ratio (C), as well as in treatments A and B, with significant differences ($P<0.05$). However, no inhibition was detected in treatment D (30:70). In contrast, no inhibitory effect was observed against *Escherichia coli* across all treatments. This suggests that the antibacterial compounds naturally present in milk, particularly in goat's milk, may be more effective against Gram-positive bacteria such as *S. aureus*, but less effective against Gram-negative bacteria like *E. coli*.

Sensory Evaluation (Hedonic Test)

The incorporation of cow's and goat's milk in Cheddar cheese production did not significantly influence consumer acceptance in terms of color, aroma, flavor, texture, or overall acceptance (Fig. 2). These results indicate that blending cow's and goat's milk during cheese fermentation can be achieved without altering consumer preference. Similar findings were reported by Doan (2019), who demonstrated that incorporating cow's and goat's milk in yogurt production did not significantly affect panelists' responses. Although cow's and goat's milk differ in chemical composition (Mourad et al., 2014; Arora et al., 2013), their combination did not negatively impact the organoleptic quality of Cheddar cheese.

The hedonic scores of Cheddar cheese ranged as follows: color 3.38–3.75, aroma 3.17–3.42, flavor 2.88–3.21, texture 3.58–3.88, and overall acceptance 3.21–3.33. These values fall within the "like" category, demonstrating that the sensory quality of the cheese remained acceptable regardless of milk blend composition.

Table 2: Antioxidant activity, total plate count, and antibacterial activity of Cheddar cheese produced from cow–goat milk blends

Treatment	Antioxidant activity (mg GAE/L)	Total Plate Count ($CFUg^{-1}$)	Inhibition Zone against *Staphylococcus aureus* (mm)	Inhibition Zone against *E. coli* (mm)
A	4.67 ±0.19 ^{a}	1.8 x 10^{4}± 0.02^{a}	9.33 ±0.04^{a}	0
B	3.94 ± 0.10 ^{b}	1.5x 10^{4} ± 0.01^{a}	7.22 ± 0.02^{b}	0
C	4.56 ± 0.33 ^{a}	4.3 x 10^{4} ± 0.04^{c}	5.73 ±0.03 ^{c}	0
D	4.16 ±0.04 ^{b}	3.2 x 10^{4} ± 0.02^{b}	0	0

Values (Mean+SD) bearing different superscripts in a column differ significantly (P<0.05).

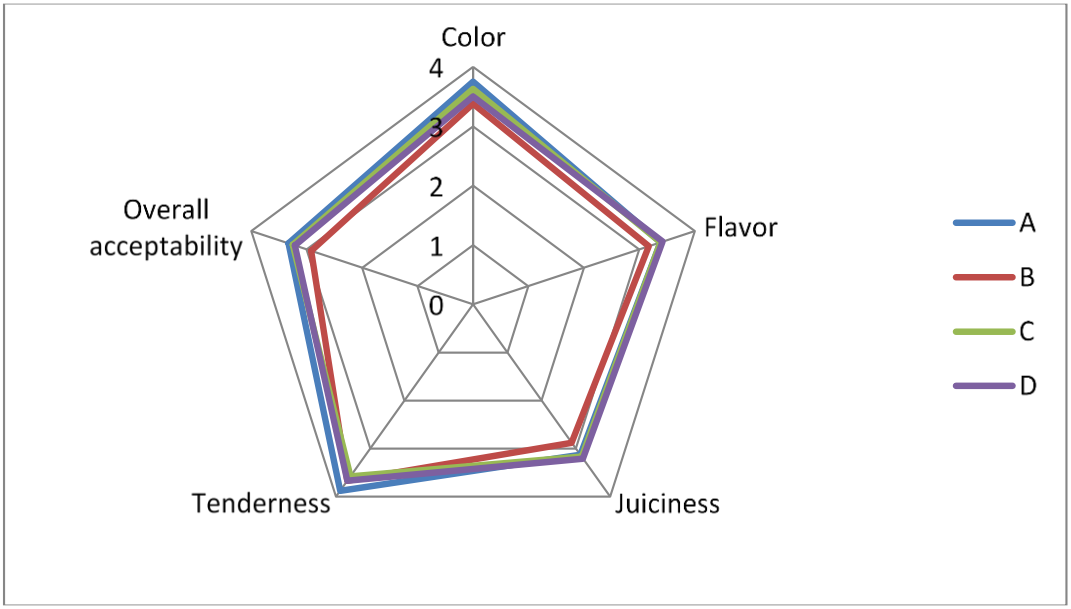

Fig. 2: Panelists' responses to Cheddar cheese produced from cow–goat milk blends.

Color Profile of Cheddar Cheese

The lightness (L*) of Cheddar cheese (Table 3) produced from pure cow's milk (A) and pure goat's milk (B) did not differ significantly, whereas a significant decrease (P<0.05) in lightness was observed in the blended treatments (C=70:30 and D=30:70). The lowest lightness value was found in treatment C (70:30 cow-to-goat milk ratio). This reduction is likely attributed to the lower fat composition of cow's milk compared with goat's milk (Arora et al., 2013), which consequently influenced the overall lightness of the cheese.

Table 3: Mean values of color quality of Cheddar cheese produced from cow–goat milk blends

Treatment	L* (Lightness)	a* (Red–Green)	b* (Yellow–Blue)
A	38.83±0.93^{a}	-3.40±0.10^{a}	13.71±0.33^{a}
B	38.34±0.62^{a}	-3.96±0.11 ^{a}	10.70±0.36^{b}
C	35.82±0.75^{b}	-3.54±0.23 ^{a}	13.13±0.54^{c}
D	36.97±0.62^{c}	-3.87±0.03 ^{a}	11.44±0.42^{d}

Values (Mean+SD) bearing different superscripts in a column differ significantly (P<0.05).

In contrast, the redness (a*) values showed no significant differences among treatments, with all four treatments consistently exhibiting low redness values. However, the yellowness (b*) values differed significantly (P<0.05), with the highest yellowness recorded in treatment A (100% cow's milk). These results indicate that milk composition, particularly fat content, plays a crucial role in determining the color attributes of Cheddar cheese, with cow's milk contributing more strongly to yellowness than goat's milk. The yellow color of milk is primarily caused by its beta-carotene content. Processed cow's milk appears yellow compared to goat's milk because goat's milk has a lower beta-carotene content; this is due to goats converting nearly all beta-carotene into vitamin A, resulting in processed goat's milk that tends to be pale or colorless (Kilcawley et al., 2018).

Texture Profile

The texture profile of Cheddar cheese produced from cow–goat milk incorporation is presented in Table 4. Neither the pure milk treatments nor the blended formulations showed significant differences in hardness, adhesiveness, springiness, cohesiveness, or gumminess. However, significant differences (P<0.05) were observed in chewiness and resilience values. One possible explanation is that the smaller fat globule size in goat's milk contributed to variations in chewiness and resilience of the resulting Cheddar cheese.

According to Lopez et al. (2018), the milk fermentation system in cheese production is a complex and dynamic process, where the natural diversity of proteolytic enzymes in milk strongly influences the final product characteristics. In this study, the combination of cow's and goat's milk particularly affected chewiness and resilience, suggesting that milk composition and fat microstructure play an important role in shaping the mechanical properties of Cheddar cheese. The elasticity of cheddar cheese made from 70% goat's milk and 30% cow's milk shows a high value. This high elasticity is attributed to the smaller micelle structure in cow's milk (220-300 nm) compared to that in goat's milk (200-500 nm), as well as the higher β-casein content and larger micelles found in cow's milk. The interaction between these proteins produces a more stable protein network and can retain moisture better. These characteristics will contribute to the durability and elasticity of the cheese during ripening (Boukria et al., 2020).

Table 4: Mean texture profile of Cheddar cheese produced from cow–goat milk blends

Variable	Incorporation of Cow's and Goat's Milk			
	A	B	C	D
Hardness	1837.91±1417.03[a]	1542.86±540.47[a]	2235.26±1434.25[a]	2501.91±811.73[a]
Adhesiveness	-52.94±39.53[a]	-126.64±229.23[a]	-258.68±433.91[a]	-334.86±704.98[a]
Springiness	0.63±0.16[a]	0.78±0.07[a]	0.67±0.17[a]	0.73±0.20[a]
Cohesiveness	0.27±0.04[a]	0.39±0.08[b]	0.30±0.04[a]	0.31±0.06[a]
Gumminess	458.16±287.64[a]	597.42±205.06[a]	653.53±389.35[a]	763.51±262.12[a]
Chewiness	267.07±129.37[a]	457.40±138.04[ab]	443.11±334.15[ab]	565.70±291.45[b]
Resilience	0.08±0.02[a]	0.17±0.03[b]	0.09±0.02[a]	0.09±0.02[a]

Values (Mean+SD) bearing different superscripts in a column differ significantly (P<0.05).

Proximate Composition

The proximate composition analysis presented in Table 5 demonstrated significant differences (P<0.05) in pH, moisture, protein, and fat contents among Cheddar cheeses produced from different milk sources. The significant differences in pH between treatment A (100% cow's milk) and the 30:70 cow-to-goat milk blend were likely due to the higher level of chemical interactions associated with goat's milk components, which contributed to a reduction in pH values (P<0.05).

Table 5: Mean proximate composition of Cheddar cheese produced from cow–goat milk blends

Treatment	pH	Moisture	Protein	Ash	Fat
A	5.84±0.09[a]	38.77±1.55[a]	26.07±0.10[a]	2.83±0.02[a]	26.95±1.54[a]
B	5.66±0.08[ab]	39.28±0.58[a]	25.25±0.77[ab]	2.70±0.08[a]	29.21±0.33[b]
C	5.56±0.31[ab]	36.34±0.93[b]	27.34±1.53[ab]	3.29±0.34[a]	28.05±1.10[ab]
D	5.45±0.19[b]	34.01±1.50[c]	27.70±1.06[b]	3.22±0.43[a]	26.80±0.67[a]

Values (Mean+SD) bearing different superscripts in a column differ significantly (P<0.05).

There is a correlation between the pH of cheddar cheese and its moisture content. The lowest pH values are found in 30% cow's milk and 70% goat's milk, which also have the lowest moisture content. Lowering the pH can extend shelf life by inhibiting the growth and development of harmful microorganisms, especially spoilage bacteria. Furthermore, a low moisture content in a product can help maintain freshness and shelf life (Susilo et al., 2023). Moisture content also contributes to the functional qualities and softness of cheese; therefore, moisture content is considered the most important component in cheese proximate (Murtaza et al., 2024). The decrease in the water content of cheddar cheese also plays a role in increasing the protein content (Oyinlola et al., 2024).

This trend was consistently reflected in moisture, protein, and fat contents, suggesting that the incorporation of goat's milk altered the chemical balance of the cheese matrix. In contrast, no significant differences were observed in ash content across treatments, indicating that milk blending did not influence the mineral composition of Cheddar cheese.

Amino Acid Profile

Table 6 shows the amino acid profile of Cheddar cheese produced from different milk blends, indicating that goat's milk and cow–goat milk combinations yielded higher total amino acid contents compared with pure cow's milk. The highest concentrations were observed in three amino acids: glutamate, proline, and leucine. Lower concentrations were recorded for aspartate, threonine, serine, valine, isoleucine, tyrosine, phenylalanine, histidine, and lysine. During the cheese ripening process, casein proteolysis produces bioactive peptides that have antioxidants and antihypertensive activities. Goat's milk cheeses, particularly those with a high β-casein content, exhibit a higher release of peptides with antioxidant activity. Peptides such as proline, histidine, glutamic acid, arginine, leucine, lysine, and tyrosine have been found to contribute to the antioxidant activity of cheeses during ripening (Iwaniak et al., 2022).

Table 6: Mean amino acid profile of Cheddar cheese produced from cow–goat milk blends

Variable	Combination of Cow's and Goat's Milk			
	A	B	C	D
Aspartic acid	1.85±0.05[a]	2.31±0.44[ab]	2.70±0.28[b]	2,20±0.32[ab]
Threonine	1.02±0.01[a]	1.24±0.16[a]	1.11±0.10[a]	1.31±0.27[a]
Serine	1.52±0.19[a]	1.63±0.10[a]	1.75±0.18[a]	1.75±0.08[a]
Glutamate	7.37±1.13[ab]	7.39±1.12[ab]	6.56±0.41[a]	8.82±0.30[b]
Proline	2.92±0.04[ab]	2.78±0.09[a]	2.47±0.53[a]	3.38±0.09[b]
Glicine	0.47±0.08[a]	0.47±0.09[a]	0.53±0.05[a]	0.50±0.04[a]
Alanine	0.80±0.21[a]	0.78±0.14[a]	0.88±0.14[a]	0.83±0.24[a]
Sistine	0.08±0.03[a]	0.07±0.04[a]	0.08±0.03[a]	0.10±0.01[a]
Valine	1.55±0.23[a]	1.96±0.18[a]	1.83±0.17[a]	1.91±0.33[a]
Methionine	0.51±0.10[a]	0.72±0.05[b]	0.75±0.07[b]	0.69±0.06[b]
Ileucine	1.41±0.10[a]	1.37±0.13[a]	1.46±0.09[a]	1.49±0.10[a]
Leucine	2.61±0.09[a]	3.18±0.22[a]	3.22±0.56[a]	3.19±0.49[a]
Tyrosine	1.30±0.01[a]	1.35±0.02[a]	1.58±0.10[a]	1.54±0.39[a]
Phenylalanine	1.24±0.04[a]	1.46±0.15[a]	1.47±0.18[a]	1.55±0.36[a]
Histidine	1.21±0.11[a]	0.92±0.47[a]	0.92±0.08[a]	1.11±0.10[a]
Lysine	1.77±0.18[a]	2.06±0.13[ab]	1.86±0.17[a]	2.35±0.41[b]
Arginine	0.91±0.17[a]	0.78±0.10[a]	0.82±0.23[a]	0.92±0.15[a]
Tryptophan	0.02±0.02[a]	0.02±0.01[a]	0.02±0.01[a]	0.02±0.01[a]
Total amino acids	28.58±1.78[a]	30.49±1.33[a]	30.02±0.23[a]	33.66±1.12[b]

Values (Mean+SD) bearing different superscripts in a row differ significantly (P<0.05).

An interesting finding across all treatments was the consistently high levels of glutamate. Glutamate is known to play multiple roles, including taste perception, intermediate metabolism, and neurotransmission. Specifically, glutamic and aspartic acids contribute to sour taste in cheese, while sweet notes are associated with amino acids such as glycine, alanine, threonine, proline, and serine. In contrast, bitter tastes are attributed to amino acids including tryptophan, valine, arginine, lysine, methionine, and leucine (Berisha et al., 2023). These results suggest that the blend of cow's and goat's milk not only influences the quantitative amino acid composition but also has implications for the sensory characteristics of Cheddar cheese.

Fatty Acid Profile

Table 7 presents the fatty acid profile of Cheddar cheese. It is well established that the fatty acid composition of cheese is largely determined by the fatty acid profile of the raw milk, with beneficial molecules being transferred from fresh milk into the final dairy

product (Nudda et al., 2021). The total fatty acid content across the four treatments showed a decrease in the blended cow–goat milk cheeses compared with cheeses made from pure cow's or pure goat's milk. The highest total fatty acid content was observed in cheese produced from pure goat's milk, followed by pure cow's milk, the 30:70 cow-to-goat milk blend, and the lowest in the 70:30 blend.

Table 7: Mean fatty acid profile of Cheddar cheese produced from cow–goat milk blends

Variable	Combination of Cow's and Goat's Milk			
	A	B	C	D
Butyric acidC4:0	1.01±0.45^{a}	0.72±0.16^{a}	1.05±0.04^{a}	0.79±0.25^{a}
Caproic acidC6:0	1.33±0.28^{ab}	1.48±0.21^{ab}	1.22±0.03^{a}	1.59±0.09^{b}
Caprylic acid C8:0	0.91±0.17^{a}	1.98±0.2^{b}	1.13±0.03^{a}	1.78±0.17^{b}
Capric acidC10:0	2.28±0.15^{a}	7.03±0.3^{d}	3.24±0.06^{b}	6.02±0.13^{c}
Undecanoic acidC11:0	0.25±0.17^{a}	0.10±0.02^{a}	0.22±0.04^{a}	0.16±0.08^{a}
Lauric acid C12:0	2.92±0.26^{a}	3.10±0.32^{a}	2.84±0.17^{a}	2.99±0.04^{a}
Myristic acid C14:0	8.85±0.27^{d}	7.25±0.10^{a}	8.18±0.07^{b}	7.47±0.12^{a}
Myristoleic acid C14:1	0.66±0.27^{c}	0.06±0.02^{a}	0.48±0.10^{bc}	0.27±0.03^{b}
Pentadecanoic acid C15:0	0.67±0.27^{a}	0.53±0.03^{a}	0.64±0.10^{a}	0.55±0.04^{a}
Palmitic acid C16:0	23.91±0.43^{c}	20.16±0.16^{a}	22.67±0.09^{b}	19.93±0.21^{a}
Palmitoleic acid C16:1	1.54±0.16^{c}	0.53±0.06^{a}	1.26±0.02^{b}	0.71±0.14^{a}
Heptadecanoic acid C17:0	0.44±0.19^{a}	0.46±0.14^{a}	0.46±0.18^{a}	0.46±0.06^{a}
Stearic acid C18:0	9.58±0.44^{a}	11.57±0.18^{b}	10.01±0.28^{a}	11.32±0.12^{b}
Elaidic acid C18:1n9t	0.44±0.09^{a}	1.94±0.15^{c}	0.64±0.08^{a}	0.89±0.09^{b}
Oleic acid C18:1n9c	18.78±0.87^{b}	19.35±0.18^{b}	18.35±0.18^{ab}	17.51±0.60^{a}
Linolelaidic acid C18:2n9t	0.09±0.05^{a}	0.17±0.02^{b}	0.10±0.01^{a}	0.16±0.02^{b}
Linoleic acid C18:2n6c	2.06±0.04^{a}	3.43±0.20^{c}	1.98±0.06^{a}	2.84±0.13^{b}
Arachidic acidC20:0	0.10±0.01^{a}	0.23±0.05^{b}	0.13±0.03^{a}	0.15±0.03^{a}
Behenic acid C22:0	0.12±0.03^{a}	0.34±0.04^{b}	0.17±0.02^{a}	0.28±0.06^{b}
Arachidonic acid C20:4n6	0.13±0.01^{ab}	0.11±0.01^{a}	0.19±0.03^{c}	0.16±0.01^{bc}
Total fatty acids	76.07±0.79^{a}	80.54±0.18^{b}	74.96±0.32^{a}	76.03±0.87^{a}

Values (Mean+SD) bearing different superscripts in a row differ significantly ($P<0.05$).

Jeong et al. (2017) reported that short-chain fatty acids such as C4 (butyric acid), C6 (caproic acid), and C10 (capric acid) are the main volatile compounds contributing to cheese aroma. The distinctive aroma of goat's milk has antioxidant potential that contributes to the sensory quality and health of the final product (Fiutak-Filipczak et al., 2021). In this study, the higher levels of capric acid observed in treatments B (100% goat's milk) and D (30:70 blend) reflect the distinctive characteristics of goat's milk, particularly its lipolytic system. This highlights the contribution of goat's milk to the unique flavor attributes of cheeses with higher proportions of goat's milk.

Conclusion

This study demonstrated that the incorporation of cow's and goat's milk in Cheddar cheese formulations significantly affected the chemical, physical, textural, antioxidant, and nutritional characteristics of the final product. The 30% cow's milk:70% goat's milk formulation produced the most favorable overall results in terms of physicochemical quality, amino acid profile, and sensory acceptance by panelists. These findings suggest that combining the two types of milk can serve as an innovative strategy for diversifying dairy products with enhanced functional properties.

The contribution of this research lies in providing scientific evidence on the potential utilization of goat's milk in the cheese industry, particularly in Cheddar cheese, to improve functional value without compromising consumer acceptance. This outcome may support the development of dairy industries based on local resources while expanding the market opportunities for blended-milk cheeses.

The main limitations of this study are the absence of shelf-life and storage stability analyses, as well as the use of a limited number of semi-trained panelists, which may not fully represent large-scale consumer preferences. Future research should include shelf-life evaluation of cow–goat milk Cheddar cheese, comprehensive analyses of the bioactivity of functional components (e.g., bioactive peptides), and large-scale consumer preference testing. Moreover, further studies on the application of cow–goat milk incorporation in other cheese types or fermented dairy products are recommended to broaden its potential use in the functional food industry.

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Data Availability: All data generated or analyzed during this study are included in this published article. Raw experimental data are available from the corresponding author upon reasonable request.

Ethics Statement: All sensory testing was conducted with the explicit and informed consent of all participants. Assessments were conducted anonymously and without coercion. Participants were informed of the purpose of the study and their right to withdraw from it at any time without consequence. All data collected was kept confidential and used solely for the purposes of this study.

Author's Contribution: Conceptualization, data curation, and manuscript editing: INSM; Physicochemical data analysis and curation: IARPP; FTIR, amino acid, and fatty acid profile analysis: NPD; Texture profile analysis and English language review: AS and English article writing and grammar templates: SMY.

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