Review Article
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Mediterranean region sheep, goat, buffalo, and cow milk composition and color parameters

Volume 14 Issue 1 - 2026

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Received: February 13, 2026 | **Published:** March 3, 2026

Abstract

This study was conducted to investigate the compositional, physical, and color characteristics of sheep, goat, buffalo, and cow milk in the Mediterranean region to examine the differences among species as well as the relationships between these characteristics. The findings indicate that milk composition and physical properties play a determining role not only in terms of nutritional value but also in the formation and perceptual characteristics of milk color. Differences observed among species with respect to basic components such as fat, protein, lactose, and solids-non-fat were also reflected in the CIELAB color parameters and total color difference (ΔE) values. In terms of color parameters, the L* value exhibited strong relationships with milk composition and certain physical properties, whereas the a*, b*, Chroma, and Hue parameters showed more selective and limited associations. Inter-species ΔE analyses revealed visually distinct color differences particularly between sheep milk and the other milk types, while goat and cow milk were found to be more similar to each other in terms of color characteristics. These findings suggest that species-specific compositional structures and physical properties play an important role in the perception of milk color.

Keywords: Mediterranean region, sheep, goat, buffalo, cow, milk composition, milk colour

Introduction

Milk is one of the most important raw materials of the milk and dairy industry, not only because it is a staple food in human nutrition but also due to its compositional and technological properties. Milk obtained from different animal species shows considerable differences in terms of chemical composition, physical structure, and processing characteristics. These differences become particularly noteworthy from the perspectives of nutrition science and cheese technology when considering cow, sheep, and goat milk, which are widely used worldwide.[1,2] Milk quality is a fundamental factor for both the protection of consumer health and the efficient and sustainable functioning of the milk and dairy industry. The chemical composition, physical properties, and technological performance of milk directly affect not only its nutritional value but also its processability, product yield, and the quality of the final product obtained. The amount and balance of basic components such as fat, protein, and lactose are especially decisive for yield and structure in cheese and fermented dairy products. In addition, milk color, coagulation properties, and hygienic status have gained importance as rapid and practical indicators in quality evaluation. In this context, the holistic assessment of milk quality emerges as a critical requirement not only in terms of nutrition but also with respect to economic value and technological suitability.

Milk color is one of the first attributes influencing consumers' perception of quality. However, milk color is not merely a visual characteristic but rather a complex trait closely associated with milk components. Fat and protein content, lactose concentration, mineral structure, carotenoids, and the light-scattering behavior of fat globules play a determining role in the formation of milk color.[3] Today, measurements based on the CIELAB color space allow milk color to be evaluated in an objective and comparable manner.[4] Especially in studies conducted on cow milk, significant relationships have been demonstrated between color parameters and fat content, hygienic quality, and certain technological properties.[5]

Compared with cow milk, sheep and goat milk are characterized by higher fat and protein contents and are therefore particularly preferred in cheese production. Sheep milk stands out due to its high curd yield and rich nutrient composition, whereas goat milk is generally characterized by lower curd firmness and moderate cheese yield.[6] These differences are mainly attributed to species-specific protein components, casein micelle structures, and the distribution characteristics of fat globules.[7]

Although the relationship between milk composition and coagulation properties has long been investigated, the direct association between milk color and these technological properties has often been considered a secondary criterion. However, recent studies indicate that milk color is not only a visual quality indicator but may also exhibit significant relationships with milk solids and curd yield.[8–10]

In this context, a study conducted by Garzón et al.[10] analyzed a total of 2,400 individual milk samples from cows, sheep, and goats, and examined in detail the relationships among milk composition, coagulation properties, and color parameters. The results revealed that sheep milk stands out in terms of cheese-making capacity, shows similarities with goat milk regarding compositional and coagulation characteristics, but is closer to cow milk in terms of color properties. Furthermore, color parameters were found to exhibit strong relationships particularly with fat and protein content and to be significantly associated with curd yield.[10]

Overall, existing studies suggest that milk color can be used as a rapid, non-destructive, and economical quality indicator in the dairy industry. Especially in cheese production, the ability to predict the technological value of milk in advance is of great importance for the efficiency of production processes. Therefore, elucidating the relationships among color, composition, and coagulation properties in milk obtained from different animal species constitutes a valuable field of research for both scientific studies and industrial applications.

Materials and methods

In this study, milk samples from sheep, goats, buffaloes, and cows were collected from privately owned farms engaged in animal production in the Mediterranean region.

The Mediterranean region is geographically located between 36°–38° North latitudes and 30°–37° East longitudes. The region is characterized by a typical Mediterranean climate, with hot and dry summers and mild, rainy winters. The altitude of the sampling locations ranges between 0 and 1,500 m; the annual average temperature is 18–20 °C, and total annual precipitation is approximately 600–1,000 mm. This agro-ecological structure of the region, together with its maquis–pasture vegetation, provides suitable environmental conditions for cattle, sheep, goat, and buffalo farming.

Milk samples were collected by hand milking after discarding the foremilk from animals in the Mediterranean region and were filled into 250 mL sterile sample containers, then transported to the laboratory under cold chain conditions (Figure 1). Milk components (fat, protein, lactose, solids-non-fat (SNF), density, pH, freezing point, etc.) were determined using a Milkana Multi Test analyzer based on the ultrasonic principle (Figure 2).

Figure 1 Milk sampling for research

Figure 2 Milkana Multi Test analyzer.

Milk color was determined using a HunterLab color analyzer according to the CIELAB system by measuring lightness (L*), redness (a*), and yellowness (b*) values (Figure 3). Hue and Chroma values were calculated from the CIELAB coordinates to evaluate the color characteristics of milk in greater detail.

Figure 3 HunterLab color. analyzer.

The Chroma (C*) value represents color saturation, while the Hue angle (h°) represents the color tone.[11] Calculations were performed using the following equations:

$$C^* = \sqrt{a^{*2} + b^{*2}}$$

$$h^\circ = \text{atan2}\left(b^*, a^*\right) \times \frac{180}{\pi}$$

where C* (chroma) represents the saturation or vividness of the color, with higher values indicating more intense and vivid coloration, and h° (hue angle) represents the color tone expressed in degrees, ranging from 0° to 360°, where 0° corresponds to red, 90° to yellow, 180° to green, and 270° to blue. When negative hue angle values occur, 360° is added to convert them into the standard positive range. The magnitude of color variation between samples was subsequently quantified using the CIELAB color difference (ΔE) formula.

$$\Delta E = \sqrt{\left(L_2^* - L_1^*\right)^2 + \left(a_2^* - a_1^*\right)^2 + \left(b_2^* - b_1^*\right)^2}$$

where ΔE represents the total color difference between two samples; L* indicates lightness, with values ranging from 0 (pure black) to 100 (pure white); a* represents the red–green color axis, where positive values indicate redness and negative values indicate greenness; and b* represents the yellow–blue color axis, where positive values indicate yellowness and negative values indicate blueness.

Descriptive statistics of the obtained data and correlation analyses between milk composition and color characteristics were performed using the SPSS software.

Results and discussion

In the study, the chemical and physical properties of milk obtained from sheep, goats, buffaloes, and cows were compared. The results of the comparative chemical composition analyses of milk from species are presented in Table 1. A total of eight different milk characteristics were examined in the study, and seven of these traits (fat, solids-non-fat (SNF), density, freezing point, temperature, lactose, and conductivity) showed statistically significant differences among the four species.

Milk composition characteristics of sheep, goat, buffalo, and cow milk produced in the Mediterranean region showed pronounced differences among species (Table 1). The highest average fat content was determined in buffalo milk (10.36%), whereas the lowest value

Citation: Sucak MG, Göncü S, Doğan S. Mediterranean region sheep, goat, buffalo, and cow milk composition and color parameters. *J Dairy Vet Anim Res.* 2026;14(1):4–9. DOI: 10.15406/jdvar.2026.14.00355

was observed in sheep milk (3.34%). Solids-non-fat (SNF) content was highest in goat milk (9.02%) and lowest in sheep milk (8.21%). In terms of density, the highest average value was recorded in cow milk (29.50), while the lowest value was found in buffalo milk (23.88). The highest protein content was determined in goat milk (3.68%), whereas the lowest average value was observed in sheep milk (3.28%). When freezing point values were examined, the lowest value was observed in sheep milk (43.93), while the highest freezing point was determined in cow milk (58.31). Regarding lactose content, the highest average value was found in cow milk (4.89%), whereas the lowest value was observed in sheep milk (4.30%). In terms of electrical conductivity, the highest average value was determined in sheep milk (9.48), while the lowest value was found in buffalo milk (2.78).

Table 1 Sheep, goat, buffalo, and cow milk in terms of composition

		Mean	St. Deviation	St. Error	Minimum	Maximum
Fat (F) (%)	Sheep	3,34	0,79	0,20	2,62	4,63
	Goat	3,97	0,10	0,27	2,84	5,62
	Buffalo	10,36	0,20	0,05	9,96	10,50
	Cow	4,17	0,82	0,31	2,97	5,43
Non-fat dry matter (SNF) (%)	Sheep	8,21	0,10	0,26	7,01	9,52
	Goat	9,02	0,29	0,08	8,63	9,48
	Buffalo	8,91	0,11	0,03	8,68	9,02
	Cow	8,94	0,46	0,18	8,39	9,60
Density (D) (kg/m³)	Sheep	25,32	0,39	1,00	21,00	31,20
	Goat	28,03	0,18	0,46	25,00	30,50
	Buffalo	23,88	0,28	0,07	23,30	24,20
	Cow	29,50	0,21	0,78	27,10	32,60
Protein (P) (%)	Sheep	3,28	0,83	0,22	2,29	4,34
	Goat	3,68	0,99	0,26	0,17	4,32
	Buffalo	3,43	0,04	0,01	3,34	3,47
	Cow	3,38	0,17	0,07	3,17	3,63
freezing point (FP) (°C)	Sheep	43,93	0,67	0,17	35,70	51,40
	Goat	49,60	0,15	0,40	47,00	51,70
	Buffalo	53,81	0,18	0,05	53,50	54,00
	Cow	58,31	0,29	0,11	55,00	62,10
temperature (T) (°C)	Sheep	28,96	0,35	0,09	28,40	29,50
	Goat	27,27	0,29	0,07	26,90	27,80
	Buffalo	22,53	0,54	0,14	21,50	23,20
	Cow	25,71	0,57	0,22	25,30	26,90
Lactose (L) (%)	Sheep	4,30	0,09	0,02	4,20	4,44
	Goat	4,37	0,04	0,01	4,29	4,42
	Buffalo	4,80	0,06	0,02	4,68	4,86
	Cow	4,89	0,26	0,10	4,58	5,25
Conductivity (Z) (mS/cm)	Sheep	9,48	0,62	0,16	8,34	10,10
	Goat	5,78	0,68	0,18	5,06	7,11
	Buffalo	2,78	0,19	0,05	2,67	3,17
	Cow	4,08	0,26	0,10	3,86	4,62

The significantly higher milk fat content observed in buffalo milk compared to the other species ($p<0.001$) is consistent with findings reported in the literature. The high fat content of buffalo milk is explained by a greater triglyceride synthesis capacity in the mammary gland and species-specific differences in fat globule structure.[12,13] The lower fat content observed in sheep milk may be related to the lactation stage of the samples and individual variation.

The lower solids-non-fat (SNF) values observed in sheep milk can be associated particularly with differences in lactose and mineral components. Lactose, which constitutes a major proportion of solids-non-fat, being higher in goat and cow milk indicates that osmotic balance in milk is regulated through lactose in these species.[14] Similarly, the relatively high SNF value in buffalo milk is considered to be consistent with its high total solids content.

The absence of a significant difference in protein content among species suggests that protein concentration may be more sensitive to feeding level, stage of lactation, and individual differences rather than species per se. Indeed, many studies have reported that protein contents of milk from different species may vary within similar ranges.[6,12] This situation may also be associated with the more genetically conservative nature of protein subcomponents.

Freezing point (FP) results showed marked differences among species ($p<0.001$). The freezing point is a parameter directly related to the concentration of dissolved substances in milk, particularly lactose and mineral salts, and is considered an indirect indicator of milk composition.[15] In this study, the higher freezing point values observed in cow milk are consistent with its higher lactose content. The lower freezing point (FP) values observed in sheep milk reflect differences in the dissolved solids profile.

The higher electrical conductivity values observed in sheep milk and lower values in buffalo milk (p<0.001) can be associated with the ionic composition of milk serum. Milk conductivity is sensitive to the concentrations of sodium, potassium, and chloride ions and is also related to udder health and epithelial permeability.[12] It is considered that inter-species physiological differences play a role in this parameter.

In order to determine the color differences among sheep, goat, buffalo, and cow milk, the descriptive color statistics and analysis results of the species are presented in Table 2.

Table 2 Color parameters of sheep, goat, buffalo, and cow milk

		Mean	St. Deviation	St. Error	Minimum	Maximum
L*	Sheep	81,54c	2,89	0,75	77,34	84,83
	Goat	87,22b	0,5	0,13	86,77	88,09
	Buffalo	89,83a	0,26	0,07	89,34	90,15
	Cow	87,39b	1,25	0,47	86,09	89,08
	Significance	0,00				
a*	Sheep	-3,28b	0,55	0,14	-3,88	-2,28
	Goat	-2,21a	0,3	0,08	-2,64	-1,81
	Buffalo	-2,47a	0,07	0,02	-2,61	-2,41
	Cow	-2,54a	0,57	0,22	-3,27	-1,8
	Significance	0,00				
b*	Sheep	7,24a	1,4	0,36	5,08	9,16
	Goat	5,83b	1	0,26	4,11	6,81
	Buffalo	5,96b	0,32	0,08	5,35	6,3
	Cow	7,13a	1,18	0,45	6	9,1
	Significance	0,001				
Chroma	Sheep	7,99a	1,24	0,32	6,13	9,95
	Goat	6,26b	0,86	0,22	4,88	7,2
	Buffalo	6,46b	0,28	0,07	5,94	6,77
	Cow	7,61a	0,99	0,38	6,68	9,3
	Significance	0,00				
Hue	Sheep	-64,94a	6,26	1,62	-74,66	-55,97
	Goat	-68,60a	5,93	1,53	-73,07	-57,29
	Buffalo	-67,36a	1,63	0,42	-68,66	-64,25
	Cow	-69,83b	6,36	2,4	62,72	78,03
	Significance	0,145				

Color parameters of sheep, goat, buffalo, and cow milk produced in the Mediterranean region showed statistically significant differences among species, with the exception of the Hue value (Table 2). In terms of lightness (L*), the highest average value was determined in buffalo milk (89.83), whereas the lowest value was observed in sheep milk (81.54). For the a* values representing the red–green axis, the highest average was found in goat milk (−2.21), while the lowest average was recorded in sheep milk (−3.28). The b* value, representing the yellow–blue axis, was highest in sheep milk (7.24) and lowest in goat milk (5.83).

When Chroma values, which indicate color saturation, were examined, the highest average was observed in sheep milk (8.00) and the lowest in goat milk (6.26), demonstrating perceptible differences in color intensity among species. With respect to Hue angles, which represent color tone, the highest value was determined in sheep milk (−64.94), whereas the lowest value was observed in cow milk (−69.83), suggesting that variations in color tone may be associated with species-specific compositional and physical differences.

Color parameters differed markedly among species ($p \leq 0.001$). The lightness (L*), red–green (a*), and yellow–blue (b*) color axes, as well as the Chroma and Hue values derived from these parameters, revealed significant variations in the optical properties of milk among species. The high L* value observed in buffalo milk indicates a brighter and whiter appearance. This may be associated with the limited presence of β-carotene in buffalo milk, as β-carotene is considered one of the main determinants of yellowish coloration in milk.[16] In contrast, the higher b* values detected in sheep and cow milk suggest that yellow tones may be more pronounced in the milk of these species. Garzón et al.[10] evaluated the relationships among colour parameters (CIELAB system), chemical composition, and coagulation properties in cow, goat, and sheep milk. They reported that L* (lightness), a*, and b* values were significantly associated with fat and protein composition, indicating that milk colour is not only a visual quality trait but also reflects compositional characteristics. Nanou et al. [17] successfully discriminated cow, goat, and sheep milk using laser-induced breakdown spectroscopy (LIBS). The observed spectral differences were attributed to interspecies variation in chemical composition and pigment content. These findings support the potential of milk colour and optical properties as biomarkers for species authentication. Zhang et al.[18] investigated metabolomic differences among goat, sheep, cow, and buffalo milk. They demonstrated that variations in pigments, fatty acids, and volatile compounds influence sensory characteristics. Buffalo milk was characterized by higher fat content and a distinct carotenoid profile, whereas goat milk exhibited a whiter appearance due to its low β-carotene concentration. Similarly, Chatzimichail et al.[19] compared cow and goat milk using non-destructive spectroscopic and chemometric approaches. Their results showed that colour and spectral parameters provided high accuracy in species-based discrimination. Overall, these studies demonstrate that milk colour varies among species, and that such differences are primarily influenced by carotenoid content, riboflavin levels, fat globule structure, and protein composition.

Chroma and Hue parameters reflect the combined effects of L*, a*, and b* values, allowing a more comprehensive evaluation of color saturation and color tone. In this study, the pronounced differences observed among species in terms of Chroma and Hue indicate that not only the chemical composition of milk but also its perceptual characteristics vary depending on animal species. The literature reports that color characteristics of milk and dairy products play an important role in consumer perception and product preferences. [12,20]

Overall, the findings demonstrate that milk obtained from different animal species differs substantially not only in terms of nutritional composition but also with respect to physicochemical and optical properties. These differences represent key factors that should be considered in milk processing, product quality, technological suitability, and consumer perception.

In order to evaluate the extent to which the differences in L*, a*, and b* values among species are visually perceptible, CIELAB color difference (ΔE) values were calculated (Table 3). This approach allows the total color difference between milk types to be quantified rather than focusing solely on changes in individual color parameters.

The CIELAB color difference (ΔE) values calculated among sheep, goat, buffalo, and cow milk indicate the presence of pronounced color differences among species (Table 3). The highest color difference was determined between sheep and buffalo milk (ΔE = 8.39), demonstrating that the color difference between these two milk types is clearly perceptible at a visual level. Similarly, high ΔE values were obtained in the sheep–goat (ΔE = 5.86) and sheep–cow (ΔE = 5.85) comparisons, indicating that these differences are easily distinguishable by consumers. In contrast, the lowest color difference was observed between goat and cow milk (ΔE = 1.35), suggesting that the color difference is only marginally perceptible. Moderate color differences were identified in the goat–buffalo (ΔE = 2.63) and buffalo–cow (ΔE = 2.71) comparisons. According to the literature, ΔE values in the range of 1–2 indicate that color differences are difficult to perceive, values between 2 and 3 indicate perceptible differences, and values above 3 indicate clearly distinguishable differences.[21,22] In this context, it is evident that color differences between sheep milk and milk from the other species are visually pronounced, whereas goat and cow milk are more similar to each other in terms of color characteristics.

Table 3 CIELAB color difference (ΔE) values among sheep, goat, buffalo, and cow milk

Inter-species comparison	ΔE
Sheep–goat comparison	5,86
Sheep–buffalo comparison	8,39
Sheep–cow comparison	5,85
Goat–buffalo comparison	2,63
Goat–cow comparison	1,35
Buffalo–cow comparison	2,71

The results of the correlation analyses between color characteristics and milk composition of sheep, goat, buffalo, and cow milk are presented in Table 4.

Table 4 Correlation values between milk components and physical properties and CIELAB color parameters

		L*	a*	b*	Chroma	Hue
Fat (F) (%)	Pearson Correlation	0,67**	0,22	-0,15	-0,19	-0,21
	Sig. (2-tailed)	0,00	0,10	0,26	0,16	0,12
Non-fat dry matter (SNF) (%)	Pearson Correlation	0,58**	,43**	0,02	0,11	0,05
	Sig. (2-tailed)	0,00	0,00	0,87	0,42	0,70
Density (D) (kg/m³)	Pearson Correlation	0,11	0,2	0,13	,41**	0,37**
	Sig. (2-tailed)	0,43	0,08	0,35	0,00	0,00
%protein (P)	Pearson Correlation	0,24	0,27	0,25	-0,03	-0,13
	Sig. (2-tailed)	0,08	0,05	0,07	0,83	0,35
Freezing point (FP) (°C)	Pearson Correlation	0,717**	,428**	0,077	,504**	,447**
	Sig. (2-tailed)	0,00	0,00	0,58	0,00	0,00
Temperature (T) (°C)	Pearson Correlation	-0,77**	-0,40**	0,25	-0,05	-0,03
	Sig. (2-tailed)	0,00	0,00	0,06	0,71	0,80
Lactose (L) (%)	Pearson Correlation	0,65**	,29*	-0,01	,50**	0,48**
	Sig. (2-tailed)	0,00	0,03	0,94	0,00	0,00
Conductivity (Z) (mS/cm)	Pearson Correlation	-0,91**	-,48**	,31*	-0,21	-0,21
	Sig. (2-tailed)	0,00	0,00	0,02	0,11	0,13

The results of the Pearson correlation analysis between milk components, selected physical properties, and color parameters are presented in Table 4. When the relationships between the L* (lightness) value and milk components were examined, positive and significant correlations were determined with fat content ($r = 0.670$; $p<0.001$), solids-non-fat (SNF) content ($r = 0.582$; $p<0.001$), freezing point ($r = 0.717$; $p<0.001$), and lactose content ($r = 0.654$; $p<0.001$). In contrast, strong and negative relationships were identified between L* and temperature ($r=-0.775$; $p<0.001$) as well as electrical conductivity ($r=-0.914$; $p<0.001$). No statistically significant relationship was observed between L* and density or protein content.

For the a* (red–green axis) value, positive and significant correlations were detected with solids-non-fat ($r = 0.438$; $p = 0.001$), freezing point ($r=0.428$; $p = 0.002$), and lactose content ($r = 0.291$; $p = 0.036$). Conversely, negative and significant relationships were identified between a* and temperature ($r = -0.402$; $p = 0.003$) as well as electrical conductivity ($r=-0.482$; $p<0.001$). The relationships between a* and fat, density, and protein content were not statistically significant.

With respect to the b* (yellow–blue axis) value, only electrical conductivity showed a negative and significant relationship with b* (r = −0.310; p = 0.025), whereas correlations between b* and the other milk components and physical properties were not statistically significant.

When the relationships between Chroma (color saturation) and milk characteristics were examined, positive and significant correlations were determined with density (r = 0.415; p = 0.002), freezing point (r = 0.504; p<0.001), and lactose content (r = 0.505; p<0.001). In contrast, no statistically significant relationships were found between Chroma and fat, solids-non-fat, protein, temperature, or electrical conductivity.

In terms of the Hue (color tone) value, positive and significant relationships were identified with density (r = 0.378; p = 0.006), freezing point (r = 0.447; p = 0.001), and lactose content (r=0.487; p<0.001). Correlations between Hue and fat, solids-non-fat, protein content, temperature, and electrical conductivity were not statistically significant.

It has been reported that milk color, particularly the L* and Chroma parameters, is closely associated with milk composition and physical structure, and that changes in fat, lactose, and mineral content affect light scattering and reflection, thereby altering the perception of brightness and saturation.[12,6] The negative relationships observed between electrical conductivity and L* and a* suggest that ion concentration and mineral balance may play a role in the perception of milk color. These findings indicate that color parameter differences arising from milk composition and physical structure should be quantitatively evaluated in terms of their visual perceptibility.

Conclusion

The color parameters in milk obtained from different animal species exhibit significant relationships with milk composition and certain technological properties and may have potential as quality assessment tools. In particular, color measurements may be used as a complementary tool in applications aimed at predicting the technological value of milk in advance, especially in milk processing and cheese production. By providing a comprehensive dataset on different milk types under Mediterranean conditions, this study constitutes a fundamental reference for future research and industrial applications related to milk quality assessment.

Acknowledgments

None.

Conflicts of interest

The authors declares that there are no conflicts of interest.

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