

## RESEARCH ARTICLE

# Sensory and bromatological characterization of artisanal fresh panela cheese made from goat's milk with a specific $\alpha$ -s1-casein genotype and cow's milk

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**Abstract:** The influence of AA and FF genotypes of  $\alpha$ -S1-casein in goat milk was evaluated in relation to the bromatological and sensory characteristics of traditionally produced regional panela cheese made from a blend of goat and cow milk. A total of 68 Saanen and Creole goats were genotyped using the PCR-RFLP. Cheese was made with milk from goats with AA and FF genotypes and in 1:1 mixtures of goat milk (GM) and cow milk (CM), the mixed-milk cheeses were as follows: GMAA+CM, GMFF+CM, GMAF+CM, and a control made from non-genotyped goat milk and cow milk (GM+CM). Cheese yield, protein, fat, and moisture contents were determined. Sensory analysis was conducted on 15 attributes using a descriptive test with an unstructured linear scale. In the Saanen breed, six goats carried the A allele and four carried the F allele. In contrast, among the Creole goats, only the F allele was detected in the three individuals analyzed, with no occurrence of the A allele. GMAA+CM exhibited the highest protein content (22.91%) and the lowest goat flavor score (3.42), while GMFF+CM presented higher fat (21.06%) and moisture content (53.81%) along with a more intense goat flavor (4.67) ( $p < 0.05$ ). No significant differences were found in cheese yield or goat odor intensity ( $p > 0.05$ ). *CSN1S1* genotyping enabled the production of goat and cow milk cheeses with a milder goat flavor, facilitating the development of products with enhanced bromatological properties and distinctive sensory profiles.

**Keywords:**  $\alpha$ -s1-casein genotype, goat milk, cow milk, panela cheese, bromatological composition, sensory analysis

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## Introduction

Artisanal cheese represents a cultural food product that supports agri-food value chains and has an important role in local economic development (Villegas de Gante and Cervantes Escoto, 2011). In Mexico, artisanal cheese production dates back to the colonial period; its production is widely accepted and distributed throughout the country (Villegas de Gante, 2012; Solís-Méndez et al. 2013). Around forty types of traditional artisanal cheese have been identified in Mexico, they are typically made from raw milk using rennet and salt, these cheeses contribute a wide variety of flavor, aromas, and textures to Mexican cuisine (Villegas de Gante and Cervantes Escoto 2011; Grass-Ramírez and Cesín-Vargas 2014). In Mexico, panela cheese represents nearly 80% of total cheese consumption, it is a white, lightly pressed cheese is known for its soft, creamy consistency, delicate texture, and mild, fresh milk flavor (Jimenez-Guzmán et al. 2009; Ramírez-López and Vélez-Ruiz 2018). Cow's milk is preferred for its mild flavor, wide availability, and lower cost (Park et al. 2007; Masotti et al. 2012).

Authentic artisanal cheese is deeply rooted in the region where it is produced, shaped by traditional, community-based knowledge passed down through generations. It is characterized by distinct sensory properties and a strong reputation tied to a specific geographical area known for producing cheese of recognizably high sensory or cultural quality. These characteristics render its production process inherently linked to its place of origin and challenging to reproduce in other regions (Villegas de Gante and Cervantes Escoto, 2011). A notable example is the panela cheese made from a blend of goat's and cow's milk, which has been traditionally produced for over 50 years in Caurio de la Rinconada, Michoacán, Mexico. Despite its strong acceptance in the local market, this artisanal cheese continues to face common challenges associated with goat's milk products, particularly their distinctive goat flavor and aroma, commonly perceived as unpleasant by consumers (Boukria et al. 2020).

At the industrial level, blending goat's and cow's milk for the production of panela cheese is becoming increasingly common. When used in appropriate proportions, goat's milk enhances the overall quality of the cheese by improving its texture, flavor, and

aroma attributes typically associated with artisanal cheeses. In Mexico, Ramírez-López and Vélez-Ruiz, (2018), evaluated the effects of different volumetric ratios of goat and cow milk on the physicochemical, textural, rheological, and sensory properties of both fresh and stored samples of four types of panela cheese. However, the study did not specifically address the reduction or elimination of goaty odor and flavor. This practice represents a viable technological strategy for developing differentiated products and also increases the cheese's nutritional value, potentially offering added health benefits to consumers (Boukria et al. 2020).

The AA genotype of the *CSN1S1* gene, which encodes goat  $\alpha$ -S1-casein, has been associated with higher milk protein content, improved cheese yield, firmer curd texture, and a noticeable reduction in the characteristic goat flavor and odor (Delacroix-Buchet et al. 1996). On the other hand, the FF genotype is associated with lower protein and casein content, weaker curd formation, reduced coagulation capacity, lower yield, higher fat content, a grainier texture, and a more pronounced goat flavor and aroma (Manfredi et al. 1993; Vassal et al. 1994). The aim of this study was to evaluate the influence of the AA and FF genotypes of goat  $\alpha$ -s1-casein on the bromatological and sensory characteristics of artisanal panela cheese made from a blend of goat's and cow's milk.

## Materials and Methods

DNA was extracted from 68 blood samples collected from goats (54 Saanen and 14 Creole); all raised under a traditional extensive management system. The *CSN1S1* gene was amplified by PCR, using the primers AS1F (52-TGGGTTGTTTCCTTCTAATGA-32) and AS1R (52-TATGCCTTCTCTTTTCTCCTC-32), as reported by Reveles-Salazar et al. (2021). These primers amplify a 574 bp fragment spanning exon 9 and portions of introns 8 and 9, which contain the A and F allelic variants of the gene. Genotyping was performed by PCR-RFLP, using 0.125  $\mu$ L of the *Xmn I* restriction enzyme, following the protocol described by Ramunno et al. (2000).

Following the traditional artisanal method used for panela cheese production in Caurio de la Rinconada, Michoacán, cheeses were made from goat milk containing the AA and FF genotypes of  $\alpha$ -S1-casein. Additionally, mixed-milk cheeses were produced by blending goat milk (GM) and cow milk (CM) in a 1:1 ratio. The combinations included: GMAA+CM, GMFF+CM, GMAF+CM, and a control cheese made with non-genotyped goat milk and cow milk (GM+CM). Natural rennet (derived from calf abomasum) was used at a concentration of 7 mL per liter of milk, along with salt. Cheese yield was calculated by dividing the weight of the resulting cheese (kg) by the volume of milk used (L) and multiplying by 100. Protein, fat, moisture, ash, and crude fiber contents were determined according to the Mexican Official Standard NOM-243-SSA1-2010 (Secretaría de Salud, 2010),

through bromatological analysis conducted at the Laboratorio de Alimentos, Fármacos y Toxicología, Facultad de Ciencias Químicas, Universidad Autónoma de Nuevo León (UANL).

Sensory evaluation was carried out by a panel of trained assessors, following the methodology proposed by Ramírez-Rivera et al. (2017), with modifications adapted to the objectives of this study. The process began with the selection and training of panelists using a questionnaire, a basic taste recognition test, and a triangle test. In the second phase, panelists evaluated 15 sensory attributes (Table 1) using an unstructured linear scale.

To assess whether significant differences existed in the bromatological composition and cheese yield among the formulations, an analysis of variance (ANOVA) was performed, followed by Tukey's post hoc test ( $p < 0.05$ ). Additionally, a correlation matrix was constructed to evaluate the relationships among the 15 sensory attributes, using InfoStat software (version 9).

## Results and Discussion

Several studies in goats have reported heterogeneous genotypic and allelic frequencies of *CSN1S1* gene variants, indicating variability across breeds and populations (Maga et al. 2009; Frattini et al. 2014; Reveles-Salazar et al. 2021). In the Saanen goats analyzed, the A variant exhibited an allelic frequency of 0.3727 and a genotypic frequency of 0.1111, whereas in Creole goats the A allele showed a frequency of 0.2857. For the F variant, both the allelic and genotypic frequencies in the Saanen breed were 0.0741, while in the Creole goats, they were 0.3214 and 0.2142, respectively (Table 2). Despite the relevance of these polymorphisms for milk production traits, data on the genotypic and allelic frequencies of the *CSN1S1* gene in Creole goats remain limited. This lack of information contains our understanding of their genetic diversity and its potential impact on milk composition and cheese quality.

In our study, no significant differences in cheese yield were observed among the different formulations (Table 3). Ramírez-López and Vélez-Ruiz (2018) reported that panela cheese made from a blend of cow's milk and non-genotyped goat's milk yielded between 13 and 14 kg per 100 liters of pasteurized milk. While this value may vary depending on milk quality and the manufacturing process, the authors likewise reported no significant differences across the various milk blend ratios used.

According to Boukria et al. (2020) blending cow's and goat's milk does not consistently result in significant changes in cheese yield, particularly within artisanal production systems where multiple factors may influence the outcome.

The influence of genotypes on cheese yield is well documented. Studies indicate that the AA genotype of the *CSN1S1* gene is associated with significantly higher cheese yields compared to

the FF genotype (Delacroix-Buchet et al. 1996; Vassal et al. 1994). This difference is mainly attributed to the higher protein and casein content in AA milk, along with its superior coagulation properties and greater retention of total solids during cheese making. In contrast, milk from goats carrying the FF genotype generally results in lower cheese yields (Grosclaude et al. 1994).

The absence of significant differences in cheese yield observed in this study may be attributed to the use of natural rennet, which is known for its variable and unpredictable enzymatic composition. Typically, natural rennet contains a fluctuating ratio of chymosin to pepsin, potentially affecting the consistency of milk coagulation and, consequently, cheese yield (Fox and McSweeney, 1998). In contrast, standardized commercial rennet offers more consistent coagulation conditions (Walstra et al. 2006). Additionally, the relatively small sample size may have limited the statistical power required to detect subtle differences among cheese formulations.

Significant differences ( $p < 0.05$ ) in protein, fat, and moisture content were observed among the various cheese formulations (Table 3). The highest protein content (22.91%) was observed in the GMAA+CM blend cheese, exceeding the minimum requirement of 17% established by the NMX-F-742-COFOCALEC-2012 standard for panela cheese (COFOCALEC, 2012). This elevated protein level is likely due to the higher casein concentration in goat's milk from animals with the AA genotype, which promotes firmer curd formation and improved water retention factors that enhance protein retention in the final product (Delacroix-Buchet et al. 1996).

High casein concentrations enhance the density of the micellar network during coagulation, facilitating more efficient protein

incorporation into the curd (Grosclaude et al. 1997; Martin et al. 1999). This elevated protein content not only improves the nutritional value of the cheese but also contributes desirable technological traits, including improved texture, greater firmness, and increased dry matter retention (Barlowska et al. 2011). Although the cheeses in this study were produced using a traditional, non-standardized method, the observed trends support the influence of genotype on cheese composition, even under less controlled production conditions.

Sant'Ana et al. (2013) found a protein concentration of 14.43% in a 1:1 mixture. Niro et al. (2014), using a G65:C35 ratio in Caciocavallo-type cheeses, reported a significantly higher protein content of 44.4%. In contrast, Ramírez-López and Vélez-Ruiz (2018) reported a protein content of 8.52% in a goat-to-cow milk blend ratio of 40:60 (G40:C60). These discrepancies may be attributed to variations in the proportions of goat and cow milk used, the type of cheese produced, the stage of ripening, and the lack of genetic characterization of the animals in the previous studies.

The GMFF+CM cheese exhibited the highest fat content (21.06%), exceeding the 20% minimum required by the NMX-F-742-COFOCALEC-2012 standard (COFOCALEC, 2012). Previous studies have reported considerable variability in the fat content of cheeses produced from blends of cow's milk and non-genotyped goat's milk. For example, Sant'Ana et al. (2013) reported a fat content of 17.78 g/100 g in cheeses made with a 1:1 cow-to-goat milk ratio and concluded that the milk proportion did not significantly influence the final fat content. Queiroga et al. (2013) found that Coalho-type cheese produced with a 1:1 mixture of cow's and goat's milk exhibited a fat content of 22.21%, which was greater than that of cheeses made exclusively from either milk type. Niro et al. (2014) produced traditional fresh

**Table 1:** Description of the sensory attributes evaluated in artisanal panela cheeses

Number	Attribute	Description
1	White color	Light shades; matte white in fresh cheeses; yellowish in aged cheeses
2	Hardness	The force necessary to cause deformation, commonly classified as soft, firm, or hard.
3	Firmness to touch	Resistance when cutting; tactile sensation (dry, moist, or firm)
4	Granularity	Smooth or grainy texture, typical of fresh or aged cheeses
5	Adhesiveness	Effort needed to detach the cheese from the palate or fingers
6	Cohesiveness	Degree of deformation before breaking; fragile if it breaks without deforming
7	Creaminess	Smooth, creamy sensation while chewing
8	Goat flavor	Distinct goat-like taste; intensity may be low, medium, or high
9	Goat aroma	Goat-like smell released during chewing
10	Milky flavor	Flavor associated with fresh milk
11	Milky odor	Milk-related aromas perceived retronasally
12	Sweet	Sweet taste detected on the tongue
13	Salty	Salty taste detected on the tongue
14	Acidic	Sourness perceived on the tongue
15	Bitter	Bitter taste perceived on the tongue

Caciocavallo-type cheeses using a blend of 65% cow’s milk and 35% goat’s milk, reporting an initial fat content of 45.9%, which progressively decreased during ripening. On the other hand, Ramírez-López and Vélez-Ruiz (2018) reported that fat content in cheese increase from 3.43% to 3.66% as the proportion of goat milk in the blend increased. Among the various formulations of fresh panela cheese, the blend with 40% goat’s milk and 60% cow’s milk yielded the highest fat content.

Among the cheeses produced, the GMFF+CM sample exhibited the highest moisture content (53.81%), however, this value remained below the 59% minimum specified by the NMX-F-742-COFOCALEC-2012 standard standard (COFOCALEC, 2012). This result is likely linked to the artisanal manufacturing process, particularly the manual pressing step, which may have promoted greater whey expulsion and consequently reduced moisture retention. Boukria et al. (2020) support this explanation, emphasizing that technological factors such as the type of coagulation and pressure applied during processing play a critical role in determining the final moisture content of cheese.

In the sensory evaluation, no significant differences ( $p > 0.05$ ) were observed in goat-like odor between the GMAA+CM and GMFF+CM cheeses samples (Table 4). Previous research has indicated that goat milk from animals carrying the AA genotype of the  $\alpha$ -S1-casein is less prone to lipolysis and the development of off-flavors such as rancid or pronounced goat-like odors (Vassal et al. 1994; Herrera et al. 2023). In this study, only fresh cheeses were evaluated, which likely limited the extent of lipolysis and proteolysis- key ripening related biochemical processes responsible for releasing free fatty acids that intensify goat odor (Atasoy and Türkođlu, 2008). Additionally, the inclusion of cow’s milk in the formulations likely diluted the concentration of volatile compounds typically present in goat milk, especially those linked to the FF genotype. Notably, 4-ethyloctanoic acid, a major contributor to goat-like odor, is absent in cow’s milk (Ha and Lindsay, 1991).

Significant differences ( $p < 0.05$ ) in goat-like flavor were observed among the cheese samples (Table 4). Notably, the GMAA+CM cheese exhibited a significant reduction in its characteristic goat

**Table 2:** Genotypic and allelic frequencies at the *CSN1S1* locus by breed

Breed		Genotypic Frequency										Allelic Frequency	
n° = 54		6	2	4	0	28	0	1	13	0	0		
	Genotypes	AA	BB	FF	AF	BA	BF	AN	BN	FN	NN	A	0.3727
Saanen		0.1111	0.0370	0.0741	0	0.5185	0	0.0185	0.2407	0	0	B	0.4167
												F	0.0741
												N	0.1296
n° = 14		0	0	3	0	8	0	0	0	3	0		
	Genotypes	AA	BB	FF	AF	BA	BF	AN	BN	FN	NN	A	0.2857
Creole		0	0	0.2142	0	0.5714	0	0	0	0.2142	0	B	0.2857
												F	0.3214
												N	0.1071

**Table 3:** Mean comparison (Tukey’s test) of cheese yield and bromatological composition of panela cheeses made with specific  $\alpha$ -S1-casein genotypes

V/FV	Means % ( $p \leq 0.05$ ) *							
	n	Protein (%)	Fat (%)	Moisture (%)	Ash (%)	Carbohydrates (%)	Cheese Yield (%)	Crude fiber (%)
GMAA	3	21.58±0.11 <sup>c</sup>	21.52±0.02 <sup>c</sup>	50.79±0.02 <sup>b</sup>	3.29±0.01 <sup>c</sup>	1.88±0.42 <sup>a</sup>	0.11±0.01 <sup>a</sup>	<0.10
GMFF	3	19.57±0.11 <sup>b</sup>	22.46±0.02 <sup>f</sup>	52.01±0.02 <sup>c</sup>	2.49±0.01 <sup>a</sup>	2.31±0.42 <sup>a</sup>	0.16±0.01 <sup>a</sup>	<0.10
GMAA+CM	3	22.91±0.11 <sup>e</sup>	17.58±0.02 <sup>a</sup>	52.41±0.02 <sup>d</sup>	3.95±0.01 <sup>f</sup>	2.1±0.42 <sup>a</sup>	0.1±0.01 <sup>a</sup>	<0.10
GMFF+CM	3	18.94±0.11 <sup>a</sup>	21.06±0.02 <sup>d</sup>	53.81±0.02 <sup>f</sup>	2.91±0.01 <sup>c</sup>	2.19±0.42 <sup>a</sup>	0.11±0.01 <sup>a</sup>	<0.10
GMAF+CM	3	22.33±0.11 <sup>d</sup>	20.93±0.02 <sup>c</sup>	50.58±0.02 <sup>a</sup>	2.72±0.01 <sup>b</sup>	2.29±0.42 <sup>a</sup>	0.12±0.01 <sup>a</sup>	<0.10
GM+CM	3	21.83±0.11 <sup>cd</sup>	20.07±0.02 <sup>b</sup>	52.65±0.02 <sup>e</sup>	3.02±0.01 <sup>d</sup>	1.62±0.42 <sup>a</sup>	0.1±0.01 <sup>a</sup>	<0.10

\*Different letters indicate significant differences ( $p \leq 0.05$ ). V = variable; FV = variation factor; ± standard error. k/L: kilograms per liter.

GMAA: Cheese made exclusively with goat milk of the AA genotype.

GMFF: Cheese made exclusively with goat milk of the FF genotype.

GMAA+CM: Cheese made with a mixture of AA genotype goat milk and cow milk.

GMFF+CM: Cheese made with a mixture of FF genotype goat milk and cow milk.

GMAF+CM: Cheese made with a mixture of AF genotype goat milk and cow milk.

GM+CM: Cheese made with a mixture of non-genotyped goat milk and cow milk.

**Table 4.** Mean comparison (Tukey's test) of sensory attributes of panela cheeses made with specific  $\alpha$ -S1-casein genotypes

V/FV	n	White Color	Hardness	Firmness	Granularity	Adhesiveness	Cohesiveness	Creaminess	Goat odor	Whey Odor	Goat Flavor	Whey Flavor	Sweet	Salty	Acidic	Bitter
<b>Cheeses</b>																
GM/AA	3	3.68 ±0.39 <sup>ab</sup>	2.58±0.48 <sup>a</sup>	3.44±0.39 <sup>ab</sup>	3.85±0.48 <sup>a</sup>	2.42±0.46 <sup>a</sup>	4.99±0.42 <sup>a</sup>	4.37±0.39 <sup>bc</sup>	4.48±0.54 <sup>a</sup>	3.80±0.43 <sup>a</sup>	5.88±0.56 <sup>b</sup>	3.84±0.43 <sup>a</sup>	1.02 ±0.26 <sup>ab</sup>	3.78±0.34 <sup>bc</sup>	2.83±0.41 <sup>a</sup>	4.11±0.54 <sup>ab</sup>
GM/FF	3	5.05±0.3 <sup>bc</sup>	2.91±0.48 <sup>a</sup>	2.47±0.39 <sup>a</sup>	4.51±0.48 <sup>a</sup>	3.42±0.46 <sup>a</sup>	3.86±0.42 <sup>a</sup>	3.36±0.39 <sup>abc</sup>	4.11±0.54 <sup>a</sup>	3.35±0.43 <sup>a</sup>	6.17±0.56 <sup>b</sup>	3.93±0.43 <sup>a</sup>	1.01±0.26 <sup>ab</sup>	2.53±0.34 <sup>ab</sup>	2.80±0.41 <sup>a</sup>	5.08±0.54 <sup>b</sup>
GMAA+CM	3	3.93±0.39 <sup>ab</sup>	6.84±0.48 <sup>b</sup>	6.98±0.39 <sup>c</sup>	5.62±0.48 <sup>a</sup>	3.13±0.46 <sup>a</sup>	4.18±0.42 <sup>a</sup>	2.52±0.39 <sup>a</sup>	2.95±0.54 <sup>a</sup>	3.08±0.43 <sup>a</sup>	3.42±0.56 <sup>a</sup>	3.14±0.43 <sup>a</sup>	1.27±0.26 <sup>ab</sup>	1.27±0.34 <sup>c</sup>	1.65±0.41 <sup>a</sup>	2.09±0.54 <sup>a</sup>
GMFF+CM	3	4.12±0.39 <sup>b</sup>	3.68±0.48 <sup>a</sup>	4.75±0.39 <sup>b</sup>	4.36±0.48 <sup>a</sup>	2.38±0.46 <sup>a</sup>	4.10±0.42 <sup>a</sup>	3.14±0.39 <sup>abc</sup>	4.11±0.54 <sup>a</sup>	3.54±0.43 <sup>a</sup>	4.67±0.56 <sup>ab</sup>	3.37±0.43 <sup>a</sup>	1.69±0.26 <sup>b</sup>	2.24±0.34 <sup>abc</sup>	1.66±0.41 <sup>a</sup>	1.91±0.54 <sup>a</sup>
GMAF+CM	3	3.79 ±0.39 <sup>ab</sup>	2.32±0.48 <sup>a</sup>	2.59±0.39 <sup>a</sup>	4.28±0.48 <sup>a</sup>	3.06±0.46 <sup>a</sup>	4.30±0.42 <sup>a</sup>	2.88±0.39 <sup>ab</sup>	3.87±0.54 <sup>a</sup>	4.07±0.43 <sup>a</sup>	4.55±0.56 <sup>ab</sup>	4.04±0.43 <sup>a</sup>	0.92±0.26 <sup>ab</sup>	2.24±0.34 <sup>a</sup>	3.25±0.41 <sup>a</sup>	5.42±0.54 <sup>b</sup>
GM+CM	3	2.19±0.39 <sup>a</sup>	3.56±0.48 <sup>a</sup>	3.83±0.39 <sup>ab</sup>	4.04±0.48 <sup>a</sup>	3.20±0.46 <sup>a</sup>	4.89±0.42 <sup>a</sup>	4.55±0.39 <sup>c</sup>	3.89±0.54 <sup>a</sup>	3.58±0.43 <sup>a</sup>	4.63±0.56 <sup>ab</sup>	3.94±0.43 <sup>a</sup>	0.51±0.26 <sup>a</sup>	3.12±0.34 <sup>abc</sup>	5.17±0.41 <sup>b</sup>	3.84±0.54 <sup>ab</sup>

Different letters indicate significant differences ( $p \leq 0.05$ ). V = Variable; FV = Variation factor. #: Points on the scale.

GMAA: Cheese made exclusively with goat's milk of the AA genotype.  
 GMFF: Cheese made exclusively with goat's milk of the FF genotype.  
 GMAA+CM: Cheese made with a mixture of goat's milk AA genotype and cow milk.  
 GMFF+CM: Cheese made with a mixture of goat's milk FF genotype and cow milk.  
 GMAF+CM: Cheese made with a mixture of goat's milk AF genotype and cow milk.  
 GM+CM: Cheese made with a mixture of non-genotyped goat's milk and cow milk.

##: Means ( $p \leq 0.05$ ) \*

**Table 5:** Correlation matrix: coefficients and significance levels of the sensory attributes evaluated in fresh panela cheeses

Attributes	White Color	Hardness	Firmness	Granularity	Adhesiveness	Cohesiveness	Creaminess	Goat Odor	Whey Odor	Goat flavor	Whey flavor	Sweet	Salty	Acidic	Bitter
White Color	1														
Hardness	-0.03	1													
Firmness	-0.12	0.95	1												
Granularity	0.32	0.89	0.76	1											
Adhesiveness	0.04	0.17	-0.14	0.36	1										
Cohesiveness	-0.79	-0.22	-0.08	-0.33	0.8	1									
Creaminess	-0.58	-0.48	-0.77	0.8	0.63	0.63	1								
Goat Odor	0.06	-0.89	-0.76	-0.91	-0.32	0.42	0.3	1							
Whey Odor	-0.25	-0.81	-0.68	-0.75	-0.32	0.6	0.6	0.6	1						
Goat Flavor	0.36	-0.75	-0.78	-0.66	-0.08	0.85	0.29	0.29	0.29	1					
Whey Flavor	0.59	0.3	-0.86	-0.93	-0.56	0.31	0.7	0.63	0.63	0.63	1				
Sweet	-0.17	0.66	0.81	0.35	-0.51	0.06	-0.28	-0.35	-0.35	-0.35	-0.72	1			
Salty	-0.72	-0.42	-0.49	-0.57	0.39	0.71	-0.92	0.19	0.19	0.19	0.73	0.39	1		
Acidic	0.1	-0.73	-0.88	-0.49	0.44	0.24	-0.64	-0.81	-0.81	-0.81	-0.92	-0.42	-0.42	1	
Bitter															1

( $P > 0.05$ )

flavor. Previous studies have shown that the AA genotype of the  $\alpha$ -s1-casein gene is associated with a lipid profile marked by higher concentrations of long-chain fatty acids such as palmitic (C16:0), stearic (C18:0), and oleic acid (C18:1) and lower concentrations of medium- and short-chain fatty acids, including caproic (C6:0), caprylic (C8:0), and capric acid (C10:0), in comparison to the FF genotype. This alteration in fatty acid composition contributes to a milder sensory profile by reducing the perception of the characteristic goat-like flavor (Delacroix-Buchet et al. 1996).

Moreover, the inclusion of cow's milk in cheese production likely contributed to the reduction in goat-like flavor, as cow's milk is predominantly composed of long-chain fatty acids, particularly palmitic (30.6%), oleic (22.8%), and stearic acid (12.2%) (Jensen, 2002), these fatty acids may dilute the concentration of volatile compounds responsible for the characteristic goat flavor, resulting in a more neutral sensory profile. In addition, cow's milk contains significantly lower levels of short-chain volatile fatty acids-such as caproic (C6:0), and caprylic (C8:0), and capric acid (C10:0)- which are key contributors to the pronounced goat taste (Chilliard et al. 2006). Several studies have shown that blending goat milk with cow milk enhances the sensory acceptability of cheese by moderating the intense flavor and aroma typically associated with pure goat milk (Queiroga et al. 2013). Therefore, this mixture may improve consumer acceptance, particularly among individuals who are averse to the strong sensory characteristics of goat cheese (Ramírez López and Vélez Ruiz, 2018; Boukria et al. 2020).

The GMFF+CM cheese exhibited a more pronounced goat-like flavor, which may be attributed to the higher concentration of short chain fatty acids, particularly caproic (C6:0), caprylic (C8:0), and capric acid (C10:0), typically present in milk of goats carrying the FF genotype (Vassal et al. 1994). Le Quééré et al. (1998) reported that the characteristic goat flavor is primarily linked to the elevated levels of both straight and branched chain fatty acids in goat milk, notably hexanoic (C6:0), octanoic (C8:0), decanoic (C10:0), along with 3 methylbutanoic, 4 methyloctanoic, and 4 ethyloctanoic acids.

These compounds are released in greater amounts in milk with low  $\alpha$ -S1-casein content, primarily due to increased lipase activity (Delacroix-Buchet et al. 1996). Furthermore, goat milk shows a higher susceptibility to spontaneous lipolysis, including enzyme activation induced by post-milking cooling (Barlowska et al. 2011). This condition, combined with the elevated concentration of medium chain fatty acids, intensifies the expression of the characteristic goat flavor (Bihaqi and Jalal, 2010).

A strong positive correlation was observed between goat flavor and goat odor ( $r = 0.85$ ) (Table 5). This correlation is attributed to the presence of short-chain volatile fatty acids in the cheese (Ha and Lindsay, 1991; Barlowska et al. 2011), these acids

simultaneously stimulate both olfactory and gustatory receptors and are considered the primary contributors to the characteristic sensory profile of goat cheese (Delacroix-Buchet et al. 1996; Haenlein, 2004; Delgado et al. 2011).

The intensity of goat flavor in the cheeses showed negative correlations with several textural attributes, particularly hardness ( $r = -0.75$ ), firmness ( $r = -0.78$ ), and graininess ( $r = -0.66$ ), this sensory pattern is consistent with previous findings in cheeses made from goat milk with carrying the FF genotype, which is associated with low expression of  $\alpha$ -S1-casein, this deficiency promotes the formation of weaker and less compact curds, resulting in cheeses with a softer texture, reduced structural firmness, and a greater tendency toward syneresis (Vassal et al. 1994; Delacroix-Buchet et al. 1996).

Likewise, goat odor also showed positive correlations with cohesiveness ( $r = 0.32$ ) and creaminess ( $r = 0.63$ ). These results are associated with the higher fat content observed in cheeses made from milk of goats carrying the FF genotype (Heil and Dumont, 1993), which directly influences cheese texture.

Negative correlations were identified between goat odor and textural attributes, including hardness ( $r = -0.89$ ), firmness ( $r = -0.76$ ), graininess ( $r = -0.91$ ), and adhesiveness ( $r = -0.45$ ). These traits are characteristic of cheeses made from FF genotype milk, which is associated with low  $\alpha$ -S1-casein expression. This deficiency leads to the formation of less dense curds and increased syneresis (Vassal et al. 1994).

Similarly, goat flavor exhibited negative correlations with hardness ( $r = -0.75$ ), firmness ( $r = -0.78$ ), and graininess ( $r = -0.66$ ), further supporting the trend toward softer textures in cheeses with more pronounced goat-like flavor. Conversely, positive correlations were found between goat flavor and creaminess ( $r = 0.52$ ), as well as whiteness ( $r = 0.36$ ), suggesting that these attributes may be linked to higher fat content and reduced coagulation strength-both influenced by the milk's compositional profile (Caroli et al. 2007; Cebo et al. 2012).

## Conclusions

The AA genotype of the *CSN1S1* gene was associated with improved bromatological quality in panela cheese, as indicated by higher protein content and a milder expression of the characteristic goat flavor and aroma in GMAA+CM cheeses. *CSN1S1* genotyping enabled the production of goat and cow milk cheeses with a milder goat flavor, resulting in products with improved bromatological properties and distinctive sensory profiles that could expand market appeal to new consumers.

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