Physicochemical analysis of full-fat, reduced-fat, and low-fat artisan-style goat cheese¹

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ABSTRACT

The objective of this study was to examine the physicochemical properties of cheese elaborated via traditional artisan methods using goat milk containing 5, 1.5, or 0.4% fat and ripened for 1, 7, 14, or 28 d. Seventy-two cheeses were produced (2 batches × 3 fat levels × 4 ripening times × triplicate). Proximal composition, pH, texture analysis, and color were recorded in each cheese. Protein and moisture were increased in cheese, and fat and fat in DM were decreased with decreasing fat in milk. Internal and external pH was higher in low-fat and reduced-fat cheese, and pH values decreased during the first 2 wk of ripening but increased slightly on d 28. Cheese fracturability, cohesiveness, masticability, and hardness increased with decreasing fat, whereas elasticity and adhesiveness decreased. Cheese lightness and red and yellow indexes decreased with decreasing fat content; during ripening, lightness decreased further but yellow index increased.

Key words: low-fat cheese, goat milk, raw milk, physicochemical property

INTRODUCTION

Over the past 15 yr, demand for goat milk and high-value goat milk products such as cheese has increased because of the increased demand for innovative products and for alternative products for consumers with cow milk intolerance (Tziboula-Clarke, 2003). Many varieties of goat milk cheese are produced around the world, and the quality of the products depends on the variety of the local animals, the milk composition, and the techniques used for manufacturing. The differences between different goat milk cheese types is mainly attributed to various physical and chemical changes that occur during the ripening process, which are highly

influenced by the chemical composition of the milk and starter culture(s) and by the presence of additives (Park, 2001; Park et al., 2007).

Currently interest exists in preserving the production of traditional cheeses. In the Canary Islands of Spain, about 17,000 t of goat milk cheese is produced per year; most of these products are made with raw milk using traditional methods and are mainly consumed following short ripening periods (about 7 d; Fresno et al., 2008). It is generally agreed that pasteurization of milk causes changes that affect the flavor of cheese. The main agents involved in the flavoring of cheese are endogenous milk enzymes, rennet, and microbial enzymes from either local wild microflora or from commercial starters or adjunct cultures. Some endogenous milk enzymes, such as lipoprotein lipase, are inactivated by pasteurization; the autochthonous microflora are also partially eliminated, with a concomitant reduction in fermentation and degradation reactions (Grappin and Beuvier, 1997; Buchin et al., 1998).

Among the low-fat foods available worldwide, low-fat dairy products are in highest demand (Drake et al., 1996) and the demand for reduced-, low- and nonfat cheese has increased significantly since 1980 (Koca and Metin, 2004). Fat plays an important role in determining the cheese characteristics. Fat affects the body and texture of the cheese because it occupies the interstitial space in the mineral and protein structural networks and contributes substantially to the quality of taste (Jameson, 1987; McGregor and White, 1990). When fat is removed, caseins have a greater influence on the development of the texture. In low-fat cheeses, proteolysis of casein is inadequate, resulting in a relatively firm texture (Mistry et al. 1996; Mistry, 2001). Low-fat products are usually characterized as having a gummy body and an atypical flavor compared with their respective full-fat varieties.

Ample current information exists on the texture characteristics of low-fat cow (Rogers et al., 2009) and ovine milk cheeses (Lteif et al., 2009), but such information is scarce for low-fat goat milk cheese and no information is available regarding the characteristics

Received February 23, 2010.

Accepted May 13, 2010.

¹This work was supported by grant AGL 2006-08444/GAN from the Spanish Government.

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of low-fat cheese generated from raw goat milk using nonindustrial procedures. The aim of this study was to analyze the chemical composition and the physical characteristics of cheese made using traditional methods from nonpasteurized goat milk containing various fat contents and ripened for different periods of time.

MATERIALS AND METHODS

Cheese Production

Animals and Cheese Formulations. Raw goat milk cheeses were elaborated according to the traditional handmade cheese practices common in the Canary Islands (Fresno and Álvarez, 2007) and were produced at the dairy farm of the Faculty of Veterinary, University of Las Palmas de Gran Canaria (Arucas, Spain). Chemical analysis and analysis of the physical and sensory cheese characteristics were performed at the Instituto Canario de Investigaciones Agrarias (La Laguna, Tenerife, Spain). Raw goat milk was obtained from an experimental herd of the Majorero goat dairy breed from the Animal Science Unit of the University of Las Palmas de Gran Canaria. Duplicate batches of experimental cheeses were produced and consisted of full-fat cheese (**FFC**), reduced-fat cheese (**RFC**), and low-fat cheese (**LCF**) ripened for 1, 7, 14, or 28 d in triplicate, resulting in a total of 72 cheese products (2 batches $\times$ 3 fat levels $\times$ 4 ripening times $\times$ triplicate).

Processing. An Elecrem skimmer (Elecrem, Fresnes, France) was used to obtain cream (35% fat content) and skim milk from 120 L of full-fat raw goat milk. Full-fat and skim milk were combined to obtain reduced-fat milk. Milk containing 3 different fat contents was therefore obtained: full-fat milk (**FFM**; 5% fat), reduced-fat milk (**RFM**; 1.5% fat), and low-fat milk (**LFM**; 0.4% fat). The same procedure was used to elaborate each type of cheese: raw milk containing 4 g/L of salt was heated in a cheese vat to 31°C. Animal rennet (Marshall rennet powder, Rhône-Poulenc Texel, Dangé-Saint-Romain, France) comprising 50% pepsin and 50% chymosin was added to obtain clotting within 35 min at 31°C. No starter cultures were added. Curd was cut with wire knives and allowed to stand an additional 5 min. More than 400 g of curd was placed in molds containing cheesecloth and pressed in a cheese press (Arroyo, Santander, Spain) at 2 kPa of pressure for 1 h. Cheese whey samples were removed for analysis. After pressing, the cheeses were 10 ± 0.1 cm in diameter and weighed 300 ± 15 g and were divided randomly into 4 groups of 6 cheeses and allowed to ripen for 1, 7, 14, or 28 d at 10 to 12°C and 80 to 85% relative humidity.

Analysis of the Physicochemical Properties of Milk, Cheese Whey, and Cheese

The proximal composition (fat, protein, lactose, DM, and nonfat solids) of each type of raw milk and cheese whey was evaluated using a DMA2001 Milk Analyzer (Miris Inc., Uppsala, Sweden). Somatic cell count was determined using a DeLaval somatic cell counter (DeLaval International AB, Tumba, Sweden), pH was determined using a GLP22 pH meter (Crison, Barcelona, Spain), and density was determined using a lactodensitometer (Alla France, Chemillé, France). Yield was calculated as the weight of cheese at 1 d of ripening divided by the initial weight of the milk. At 1, 7, 14, and 28 d of ripening, representative samples from each cheese were analyzed for proximal composition (fat, protein, moisture, and DM fat) using an Instalab 600 Product NIR Analyzer (Dickey-John Inc., Minneapolis, MN) according to Adamopoulos et al. (2001). pH was measured at 3 internal (in the cheese center) and 3 external (1 cm from external cheese surface) locations for each cheese. Prior to texture analysis, a 0.5-cm layer was removed from the upper surface of each cheese to obtain a regular surface. Texture was analyzed using a cylindrical compression probe (samples were double compressed to 75% of their original height at a compression speed of 2 cm/min) in a TA-XT2i Texture Analyzer (Stable Micro Systems Ltd. Godalming, UK). Three cylindrical samples (2 cm in diameter and 5 cm in height) of each cheese were analyzed to determine the fracturability, hardness, cohesiveness, adhesiveness, and elasticity; masticability was indirectly determined (hardness $\times$ cohesiveness $\times$ elasticity). A Minolta colorimeter CR-400/410 (Illuminant D65, Konica Minolta, Osaka, Japan) was used to determine lightness (L^*), yellow index (b^*), and red index (a^*) for each cheese. Measurements were taken at 4 external and 4 internal locations.

Statistical Analysis

Statistical analyses were performed using SAS (version 9.00, SAS Institute Inc., Cary, NC). The ANOVA procedure was used to compare physicochemical properties of milk and cheese whey. The MIXED procedure for repeated measurements was used to evaluate the effect of differing fat content and ripening time on the chemical composition, texture, and color of the raw goat milk cheeses. Tukey's test was used to evaluate the differences between groups.

RESULTS AND DISCUSSION

Milk and Cheese Whey

The physicochemical properties of the raw goat milk and cheese whey are shown in Table 1. Milk and cheese

Table 1. Proximal composition, pH, SCC, and density of full-fat milk (FFM), reduced-fat milk (RFM), low-fat milk (LFM), and cheese whey

Item	Raw goat milk				Whey			
	FFM	RFM	LFM	SEM	FFM	RFM	LFM	SEM
pH	6.77 ^a	6.72 ^a	6.64 ^b	0.02	6.60	6.58	6.57	0.01
SCC, $\times 10^3$ cells/mL	1,753	1,811	1,795	63.53	173 ^a	165 ^a	99 ^b	9.55
Fat, %	5.08 ^a	1.57 ^b	0.40 ^c	0.48	0.54 ^a	0.07 ^b	ND ¹	0.06
Protein, %	3.47	3.35	3.33	0.04	1.07	0.96	1.07	0.04
Lactose, %	4.59 ^b	4.84 ^a	4.97 ^a	0.05	5.45	5.48	5.45	0.03
DM, %	14.00 ^a	10.51 ^b	9.45 ^c	0.47	7.49 ^a	6.92 ^b	6.87 ^b	0.07
Density, g/cm ³	1.030	1.032	1.033	<0.01	1.023	1.026	1.026	<0.01

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹ND = not detectable.

whey pH decreased with decreasing milk fat content. In contrast, Rudan et al. (1999) observed an increase in pH when fat content in milk was reduced in Mozzarella cheese. Milk SCC ranged from 1,753 to 1,811 $\times 10^3$ cells/mL. The SCC in cheese whey after cheese manufacturing was 9.8, 9.1, and 5.5% of that in FFM, RFM, and LFM, respectively. Reduction of milk fat did not alter the milk SCC, but the SCC was lowest in cheese whey produced from LFM. Removal of fat may result in the formation of a stronger paracasein network (Banks, 2004), allowing for higher somatic cell retention in the LFM curd than in FFM and RFM curd. For FFM, milk fat percentages were in accordance with previous results for the same breed (Fresno and Álvarez, 2007). Milk and cheese whey fat percentages were decreased when fat was reduced by centrifugation in a milk skimmer. The fat percentage in cheese whey decreased according to the fat content of the milk from which it was produced; FFM cheese whey contained 0.54% fat, whereas RFM cheese whey contained 0.07% fat. No fat content was detectable in LFM cheese whey. The fat retention in the cheese products was higher as the fat content of the milk decreased. Rudan et al. (1999) suggested that when high-fat milk is used to make cheese, the curd matrix reaches the maximum fat-holding capacity. The optimum milk fat content should therefore be established to minimize fat loss in the cheese whey; however, it is also possible to reuse the cheese whey when cheeses are elaborated with high-fat milk.

The protein content in milk did not significantly decrease as fat was removed by centrifugation (Table 1). The amount of protein in whey was 3 times lower than in the milk from which it was produced, but no significant differences between the 3 types of cheese whey were observed. It has been reported that as the fat milk content decreases, protein increases and DM decreases (Rudan et al., 1999; Kahyaoglu and Kaya, 2003; Madadlou et al., 2005). Milk lactose ranged from 4.5 to 5%, increasing significantly as milk fat content

decreased. However, the 3 types of cheese whey had similar lactose content. The removal of fat resulted in a slightly increased milk density.

Cheese Yield

As expected, cheese yield decreased by reducing fat in goat milk. Cheese yields for FFC, RFC, and LFC were 16.6 ± 0.54 , 13.9 ± 0.26 , and $12.4 \pm 0.33\%$, respectively. An overall reduction in cheese yield is inevitable in the production of cheese from low-fat milk (Romeih et al., 2002) because the total amount of fat removed is not equal to the amount of moisture added (Mistry, 2001); therefore, the sum of the casein and fat content of milk, which are the principal components determining cheese yield, are reduced (Romeih et al., 2002).

Chemical Composition of Cheese

Table 2 shows the proximal composition and pH (external and internal) of cheeses during 28 d of ripening. As was expected, cheese fat content was higher in FFC than in RFC and LFC during the ripening period. The percentage fat in DM was higher in FFC than in RFC or LFC at all days tested during ripening. For all cheese (FFC, RFC, and LFC) the percentage fat in DM increased significantly during the ripening period because of moisture reduction. These values were within the ranges required by Spanish regulation for full-fat (60–45% fat in DM), half-fat (45–25% fat in DM), and low-fat (25–10% fat in DM) cheese designations.

On d 1 of ripening, the protein content was higher in LFC than in RFC and FFC. Throughout ripening, the difference between the protein content in LFC compared with RFC or FFC significantly increased. The moisture was higher in LFC than in RFC or FFC at 1 d of ripening and decreased in all 3 cheese types throughout the study because of surface water evaporation. The FFC protein content was close to the values reported

Table 2. Proximal composition and external and internal pH of full-fat cheese (FFC), reduced-fat cheese (RFC), and low-fat cheese (LFC) at 1, 7, 14, and 28 d of ripening

Item	Day of ripening				SEM
	1	7	14	28	
Fat, %					
FFC	18.48 ^{d,x}	22.19 ^{c,x}	25.01 ^{b,x}	28.61 ^{a,x}	0.89
RFC	9.38 ^{b,y}	10.69 ^{b,y}	12.17 ^{ab,y}	13.61 ^{a,y}	0.39
LFC	1.12 ^{c,z}	2.60 ^{bc,z}	4.43 ^{b,z}	8.81 ^{a,z}	0.64
Fat in DM, %					
FFC	37.88 ^{d,x}	41.03 ^{c,x}	44.75 ^{b,x}	47.93 ^{a,x}	0.87
RFC	19.54 ^{c,y}	21.93 ^{b,y}	24.85 ^{a,y}	26.78 ^{a,y}	0.68
LFC	2.48 ^{d,z}	5.79 ^{c,z}	9.88 ^{b,z}	18.08 ^{a,z}	1.28
Protein, %					
FFC	18.94 ^{b,z}	20.51 ^{a,z}	20.47 ^{a,z}	19.96 ^{a,y}	0.18
RFC	20.97 ^{c,y}	23.01 ^{b,y}	24.38 ^{a,y}	24.65 ^{a,y}	0.35
LFC	22.84 ^{d,x}	25.90 ^{c,x}	29.37 ^{b,x}	32.66 ^{a,x}	0.80
Moisture, %					
FFC	46.95 ^{a,z}	45.92 ^{a,z}	44.12 ^{b,z}	40.32 ^{c,z}	0.57
RFC	52.00 ^{a,y}	51.61 ^{a,y}	50.98 ^{a,y}	49.20 ^{b,y}	0.29
LFC	55.69 ^{a,x}	55.28 ^{a,x}	55.15 ^{a,x}	51.18 ^{b,x}	0.41
External pH					
FFC	6.58 ^a	5.03 ^b	4.92 ^c	4.90 ^{c,x}	0.15
RFC	6.57 ^a	5.10 ^b	4.89 ^c	5.01 ^{b,y}	0.14
LFC	6.59 ^a	5.10 ^c	4.99 ^d	5.38 ^{b,z}	0.13
Internal pH					
FFC	6.58 ^a	4.99 ^b	4.74 ^{c,y}	4.81 ^{c,z}	0.16
RFC	6.56 ^a	5.06 ^b	4.82 ^{d,y}	4.94 ^{c,y}	0.15
LFC	6.58 ^a	5.08 ^c	4.91 ^{d,x}	5.32 ^{b,x}	0.14

^{a-d}Means within a row with different superscripts differ ($P < 0.05$).

^{x-z}Means within a column with different superscripts differ ($P < 0.05$).

for Canarian goat cheeses by Fresno et al. (2005) for Palmero cheese and by Álvarez et al. (2007) for Majorero cheese. According to the literature (Bryant et al., 1995; Rudan et al., 1999; Lteif et al., 2009), low-fat cheeses contain significantly higher amounts of protein and moisture than their respective full-fat cheeses. Fat and moisture act as fillers in the casein matrix of the cheese. When the fat content is reduced, moisture does not replace the fat equivalents (Rudan et al., 1999), which results in higher percentages of protein as the fat content decreases, thereby increasing the ratio of protein to DM.

The external pH was approximately 6.6 in FFC, RFC, and LFC at 1 d of ripening. These values were similar to the typical values reported for cheese from goat milk produced in the Canary Islands (pH 6.6–6.7; Fresno and Álvarez, 2007), were within the range reported by Martín-Hernández and Ramos (1984) and Juárez et al. (1991) for goat cheeses produced in Spain, and were also very similar to values obtained by Álvarez et al. (2007) for Majorero cheese. Similar results were observed for the internal pH at 1 d of ripening.

During the first and second weeks of ripening, external and internal pH values decreased in all cheese groups. At 28 d of ripening, the pH increased in RFC and LFC, likely because of the release of basic AA and because of NH_3 and lactate decomposition (Alais, 1985).

In FFC at 28 d of ripening, the pH value was similar to that observed at 14 d of ripening. The pH increase observed on d 28 in RFC and LFC may be attributed to a concomitant decrease in the level of moisture in nonfat solids and, hence, in the lactate:protein ratio (Fenelon and Guinee, 2000). At 7 d of ripening no differences in external and internal pH were observed between cheese groups. At 14 d of ripening the external pH was the same between cheese groups but the LFC had a higher internal pH value. This difference was more pronounced at 28 d of ripening. Taken together, these data indicate that as the fat was reduced, the external and internal pH increased. Small increases in moisture in nonfat solids led to relatively large increases in available water, which in turn resulted in increases in the activity of microorganisms and enzyme and the degree of proteolysis in cheese (Ruegg and Blanc, 1981).

Instrumental Analysis of Cheese Texture

Texture, particularly in cheese, is one of the most important attributes that helps to determine the identity of a product. Casein gels in the milk from various livestock species (cow, goat, sheep) strongly influence the rheological properties and texture of the cheese and other dairy products that are produced from the milk (Tunick, 2000).

Table 3. Texture analysis or texture profiles of full-fat cheese (FFC), reduced-fat cheese (RFC), and low-fat cheese (LFC) at 1, 7, 14, and 28 d of ripening

Item	Day of ripening				SEM
	1	7	14	28	
Fracturability					
FFC	20.34 ^{b,y}	17.35 ^{b,y}	13.72 ^{b,y}	37.53 ^{a,z}	2.67
RFC	35.10 ^{b,zy}	26.28 ^{b,zy}	35.30 ^{b,x}	83.48 ^{a,y}	6.10
LFC	39.62 ^{b,x}	36.38 ^{b,x}	45.12 ^{b,x}	190.04 ^{a,x}	14.10
Hardness					
FFC	24.91 ^{b,y}	21.37 ^{b,y}	21.77 ^{b,z}	51.32 ^{a,z}	3.11
RFC	44.13 ^{b,x}	38.00 ^{b,x}	40.33 ^{b,y}	106.47 ^{a,y}	6.54
LFC	57.14 ^{b,x}	46.02 ^{b,x}	59.32 ^{b,x}	192.60 ^{a,x}	13.05
Cohesiveness					
FFC	0.17 ^{ab,y}	0.18 ^{a,y}	0.14 ^{b,z}	0.13 ^{b,z}	0.01
RFC	0.18 ^{b,y}	0.18 ^{b,y}	0.22 ^{a,y}	0.24 ^{a,y}	0.01
LFC	0.21 ^{c,x}	0.22 ^{c,x}	0.32 ^{b,x}	0.42 ^{a,x}	0.02
Adhesiveness					
FFC	0.40 ^{c,x}	0.96 ^{b,x}	2.41 ^{a,x}	2.35 ^{a,x}	0.19
RFC	0.03 ^{c,y}	0.39 ^{b,y}	1.22 ^{a,y}	0.33 ^{bc,y}	0.10
LFC	0.01 ^{c,y}	0.14 ^{bc,y}	1.11 ^{a,y}	0.40 ^{b,y}	0.10
Elasticity					
FFC	71.02 ^{a,x}	64.69 ^{b,x}	66.20 ^{ab,x}	60.21 ^{b,x}	1.07
RFC	67.91 ^{a,xy}	57.30 ^{b,y}	58.91 ^{b,y}	51.56 ^{c,y}	1.48
LFC	63.76 ^{a,y}	51.54 ^{b,z}	53.18 ^{b,z}	38.21 ^{c,z}	2.16
Masticability					
FFC	301.26 ^y	259.32 ^y	209.54 ^z	409.08 ^z	21.60
RFC	541.28 ^{b,xy}	423.62 ^{b,xy}	522.88 ^{b,y}	1,288.03 ^{a,y}	79.98
LFC	772.58 ^{bc,x}	537.88 ^{c,x}	955.67 ^{b,x}	3,071.98 ^{a,x}	224.06

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

^{x-z}Means within a column with different superscripts differ ($P < 0.05$).

Table 3 shows the texture analysis of FFC, RFC, and LFC during the ripening period. Fracturability was significantly higher in LFC than in RFC or FFC at all ripening times examined; statistical differences in hardness were observed only between LFC and FFC at 1 and 7 d of ripening. Removal of fat has been shown to result in the formation of a much tighter paracasein network and produce a more firm cheese (Banks, 2004). Similarly, Küçüköner and Haque (2006) and Rogers et al. (2009) concluded that the hardness of Cheddar cheese increased as the fat decreased. On d 28 of ripening, fracturability and hardening increased significantly for all cheeses. This can be related to decreased moisture (Buffa et al., 2001; Fresno et al., 2006).

Cohesiveness, which results from the force exerted by internal links in the food, was higher in LFC than in RFC or FFC. Similar results were reported by others (Bryant et al., 1995; Rudan et al., 1999; Sahan et al., 2008) in which reduction of fat significantly increased the cohesiveness values. Adhesiveness was lower in RFC and LFC than in FFC during the course of ripening, increased in the 3 types of cheeses until d 14, and decreased significantly on 28 d of maturation in RFC and LFC. Elasticity of FFC decreased slightly over the 28-d ripening period but decreased significantly in RFC and LFC. Differences between the 3 types of cheeses

were observed; specifically, RFC and LFC were much less elastic than FFC, as described for Cheddar cheese (Küçüköner and Haque, 2006). In Kashar cheese (Sahan et al., 2008), elasticity was reported to decrease with age but low-fat cheese had the highest value throughout ripening. Masticability, defined as the energy required to chew the cheese samples, was more or less constant over the 28-d ripening period for FFC; it increased with ripening in RFC and LFC and was higher in LFC than FFC and RFC at all 4 ripening times examined.

Instrumental Analysis of Cheese Color

Lightness decreased during maturation, and external lightness values were always lower than internal values, except in LFC at 28 d of ripening (Table 4 and 5). The decrease in lightness during storage is probably associated with increased protein hydration, which reflects a decrease in the number of free moisture droplets and thus a reduced degree of light scattering (Sheehan et al., 2005). Khosrowshahi et al. (2006) also reported that whiteness decreased in Iranian white cheese during ripening. In a solid material such as cheese, light penetrates the superficial layers and is scattered by milk fat globules (Lemay et al., 1994) and whey pockets (Paulson et al., 1998). As ripening progresses, whey in

Table 4. External color analysis of full-fat cheese (FFC), reduced-fat cheese (RFC), and low-fat cheese (LFC) at 1, 7, 14, and 28 d of ripening

Item ¹	Day of ripening				SEM
	1	7	14	28	
L*					
FFC	91.41 ^a	85.98 ^{b,x}	80.16 ^{c,x}	77.88 ^{d,x}	1.12
RFC	91.13 ^a	80.81 ^{b,y}	76.26 ^{c,y}	75.94 ^{c,zy}	1.38
LFC	91.95 ^a	78.98 ^{b,y}	72.55 ^{c,z}	74.32 ^{c,y}	1.60
a*					
FFC	-1.31 ^{b,x}	-0.69 ^{a,x}	-0.92 ^{a,x}	-0.81 ^{a,x}	0.07
RFC	-1.90 ^{b,y}	-1.24 ^{a,y}	-2.10 ^{b,y}	-1.92 ^{b,y}	0.11
LFC	-2.47 ^{c,z}	-1.94 ^{a,z}	-2.97 ^{b,z}	-2.23 ^{a,y}	0.09
b*					
FFC	10.52 ^c	16.10 ^{b,x}	18.45 ^{a,x}	18.55 ^{a,x}	0.78
RFC	11.04 ^b	13.40 ^{a,y}	15.01 ^{a,y}	14.58 ^{a,y}	0.46
LFC	10.26 ^b	14.27 ^{a,xy}	12.87 ^{a,z}	12.88 ^{a,y}	0.39

^{a-d}Means within a row with different superscripts differ ($P < 0.05$).

^{x-z}Means within a column with different superscripts differ ($P < 0.05$).

¹L* = lightness; a* = red index; b* = yellow index.

serum pockets diffuses from the cheese body out into the brine, accompanied by moisture loss. The surface area occupied by light-scattering centers therefore decreases.

As milk fat decreased, external and internal red index values varied during the ripening of each type of cheese but were higher in RFC and LFC than in FFC. On the other hand, yellow index on d 1 of ripening was similar in all cheeses and increased during maturation. According to Rohm and Jaron (1996) and Fresno et al. (2006), many biochemical modifications occur in the maturation process of cheeses. In addition, cheeses acquire aromas and flavors and reach darker shades and increased hue angles, which results in increased yellowing.

CONCLUSIONS

Fat reduction of handmade raw milk cheeses produced using traditional methods has important effects on the chemical composition, pH, texture, and color of the resulting cheese product. As fat was reduced in milk, cheese yield decreased and protein and moisture percentages increased in cheese. Ripened (28 d) low-fat cheese displays higher fracturability, hardness, cohesiveness, and masticability values than full-fat cheese; conversely, low-fat cheese was less elastic and yellow than full-fat cheeses. All these physicochemical characteristics resulting from reducing the fat in cheese must be evaluated under a sensorial prism in the future.

Table 5. Internal color analysis of full-fat cheese (FFC), reduced-fat cheese (RFC), and low-fat cheese (LFC) at 1, 7, 14, and 28 d of ripening

Item ¹	Day of ripening				SEM
	1	7	14	28	
L*					
FFC	92.79 ^a	89.75 ^b	87.77 ^{bc,x}	86.31 ^{c,x}	0.61
RFC	93.06 ^a	89.94 ^b	85.83 ^{c,x}	84.25 ^{c,x}	0.90
LFC	93.28 ^a	89.07 ^b	80.13 ^{c,y}	64.98 ^{d,y}	2.31
a*					
FFC	-1.25 ^{ab,x}	-1.11 ^{a,x}	-1.33 ^{b,x}	-1.24 ^{ab,x}	0.05
RFC	-1.85 ^{a,y}	-1.90 ^{b,y}	-2.47 ^{c,y}	-2.64 ^{c,y}	0.07
LFC	-2.32 ^{a,z}	-2.64 ^{b,z}	-3.35 ^{c,z}	-3.19 ^{c,z}	0.10
b*					
FFC	8.21 ^c	10.31 ^{b,xy}	11.43 ^{a,x}	11.51 ^a	0.29
RFC	8.24 ^c	9.98 ^{b,y}	11.17 ^{a,x}	11.63 ^a	0.29
LFC	7.89 ^c	10.57 ^{b,x}	10.41 ^{b,y}	11.94 ^a	0.32

^{a-d}Means within a row with different superscripts differ ($P < 0.05$).

^{x-z}Means within a column with different superscripts differ ($P < 0.05$).

¹L* = lightness; a* = red index; b* = yellow index.

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