Soft goats' cheese enriched with polyunsaturated fatty acids by dietary supplementation: manufacture, physicochemical and sensory characterisation

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Abstract Modifying the lipid composition of milk and dairy products, to improve their nutritional properties, without negatively altering their technological, sensorial and functional qualities, constitutes a challenge for the dairy sector. This study was performed to increase the polyunsaturated fatty acids (PUFA) and decrease the saturated fatty acids (SFA) content of goats' milk, under real field conditions and production, by means of altering the animals diet. The effect of these changes were characterised during the manufacture of soft ripened cheese and assessing the impact on physicochemical and sensorial characteristics. Two groups of 30 crossbreed Alpine dairy goats were fed either a control diet or a diet supplemented with oilseeds providing 50.4 g UFA.goat⁻¹.day⁻¹ or 69.6 g UFA.goat⁻¹.day⁻¹ which supplied respectively 1.4 and 2.4 % of alpha-linolenic acid (ALA). Supplementing the feed of dairy goats with PUFA was shown to have beneficial effects on the FA composition of goat's milks and cheeses: (1) an increase in the content of ALA (18:3n-3; from 0.78 to 1.78 g.100 g⁻¹ of total FA) and rumenic acid (main CLA; from 0.75 to 1.27 g.100 g⁻¹ of total FA); (2) a decrease in the n-6/n-3 PUFA ratio (from 4.6 to 2) and the overall SFA content (from 66 to 60.4 g.100 g⁻¹ of total FA). The corrected cheese yield was higher for the supplemented milks (16.3 %) in comparison to the control milks (15.4 %). Both cheeses showed a similar evolution in the levels of proteolysis and lipolysis with no flavour defects being detected. Cheese sensory

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scores for the two types of cheeses were similar. Hence, healthier goats' milk and cheese FA profiles were obtained with good sensorial characteristics.

富含多不饱和脂肪酸软质山羊奶干酪的特性研究

摘要：调整乳和乳制品中脂质组成，提高其营养特性，并保持乳制品的加工、感官和功能特性是当今的研究热点。本研究是在保持生产工艺不变的前提下，通过改变动物饲料的组成，以增加山羊奶中多不饱和脂肪酸含量和减少饱和脂肪酸的含量，并评价饲料组成变化对软质成熟干酪的物化和感官特性的影响。将30只杂交的阿尔卑斯奶山羊分成两组：一组为对照组，另一组每天每只山羊提供含50.4g不饱和脂肪酸的油菜籽和1.4%的 α -亚麻酸(ALA)，或者提供含69.6g不饱和脂肪酸的油菜籽和2.4%的 α -亚麻酸。饲料中多不饱和脂肪酸含量显著地影响羊奶和羊奶干酪的脂肪酸组成：(1)ALA(18:3n-3)的含量从0.78 g·100 g⁻¹(总脂肪酸)增加到1.78 g·100 g⁻¹(总脂肪酸)；亚油酸(主要成分CLA)的含量从0.75 g·100 g⁻¹增加到1.27 g·100 g⁻¹；(2)多不饱和脂肪酸n-6/n-3比值从4.6下降到2，以及总饱和脂肪酸从66 g·100 g⁻¹下降到60.4 g·100 g⁻¹。补充过饲料的山羊奶加工成干酪的产量为16.3%，高于对照组的15.4%。两种干酪的蛋白酶解和脂肪酶解的变化相似，并且没有检测出干酪风味缺陷。两种类型干酪的感官风味分数相似。因此，通过补充含有多不饱和脂肪酸的饲料，能够获得有益于人体健康的山羊奶和更合理脂肪酸组成的干酪，同时干酪还具有良好的感官特性。

Keywords Milk · Goats' cheese · Fatty acid · Fat supplementation · Sensory analysis

关键词 奶 · 山羊奶干酪 · 脂肪酸 · 补充脂肪 · 感官分析

1 Introduction

The interest in dairy products manufactured from goats' milk is growing worldwide. This was reflected by an increase of 58 % in the population of goats worldwide between 1980 and 2000 while the population of cows increased by only 10 % (Haenlein 2004). Similarly, in France, the production of goats' cheeses multiplied threefold over the last 20 years, from 28,500 tons in 1988 to 89,500 tons in 2008 (CNIEL 2011). The production of goats' milk in France in 2010 was over 630 million L (Raynal-Ljutovac et al. 2011).

Consumers are becoming increasingly attentive to their health and to the nutritional value of foods, and in particular fatty acid (FA) composition of dairy products. Health authorities recommend a decrease in the consumption of certain saturated fatty acids (SFA; C12:0, C14:0 and C16:0) that have been reported to be implicated in cardiovascular diseases (Hu et al. 2001) and to keep the intake of *trans*-FA as low as possible. Increasing the consumption of polyunsaturated fatty acids (PUFA) and of fats with a higher n-3/n-6 FA ratio has also been highly encouraged for the improvement of human health. Studies have also reported interesting properties for the

isomers of conjugated linoleic acid (CLA) specific to dairy products (Sanz Sampelayo et al. 2007). Goats' milk fat contains a high amount of SFA (i.e. about 67 % of total FA) with significant levels of medium-chain SFA (i.e. 15–32 % of total FA), and low levels of PUFA (i.e. about 3 % of total FA) (Blasi et al. 2008; Chilliard et al. 2003). Over the last 50 years, the intensification of goat production has caused a change in the composition of milk produced (FA composition, fat and protein contents). Likewise, production methods are moving increasingly towards the stall-fed system with associated consequences: firstly, low green forage intakes induce a decrease in goats' milk PUFA content and an increase in SFA content, and secondly, this modified milk FA composition decreases the nutritional quality of goats' dairy products (Schmidely and Sauvant 2001).

For the transformers of goats' milk, proteins and fat constitute the useful dry matter (DM). Indeed, fat, total solids and protein contents provide strong predictions of soft goat cheese yield ($R^2=0.81$, 0.79 and 0.73, respectively) (Zeng et al. 2007). In addition, the specific organoleptic characteristics of goats' cheese come from the milk composition and depend on the balance between a large number of compounds (Carunchia Whetstine et al. 2003). Thus, the goat dairy industry has expectations regarding the amount of milk produced, the chemical composition of milk, the ability of goats' milk to be transformed into dairy products and the nutritional and sensorial quality of goat dairy products.

Numerous studies have been performed which examine the possibility of changing the composition of goats' milk, particularly its FA profile, by modifying the diet of the goats (Chilliard et al. 2003, 2006; Sanz Sampelayo et al. 2007). However, studies investigating the consequences of such dietary changes on the transformation of goats' milk into cheeses are scarce and these consequences are far from being fully understood and need to be better assessed. Hence, the aims of this study were: (1) to assess the effect of goats' diet supplementation with vegetable oils and oilseeds rich in PUFA (particularly C18:2n-6 and C18:3n-3) on the concentration of PUFA, CLA and the saturated/unsaturated FA ratio in milk and (2) to evaluate the effect of this supplementation on soft goats' ripened cheese physicochemical characteristics (i.e. composition of fat and protein, cheese making parameters such as kinetics of acidification and draining, cheese yield, proteolysis, lipolysis and sensorial quality).

2 Materials and methods

2.1 Animals and dietary treatments

Two groups of 30 dairy Alpine goats were used, the control group (C-group) and the supplemented group (S-group), under real conditions of production in a commercial farm (La Blanchetière, 44370 Belligné, France). Each group of goats contained 23 multiparous and 7 primiparous, with a similar rank of lactation and stage of lactation. In each group, animals possessed strong and medium genotype of α s1-casein (homogeneous groups), reflecting the selection of goat herds which has been performed in France over the past 20 years (Raynal-Ljutovac et al. 2011). In February 2009 (week 9), 4 weeks before goats' parturition, allotment was performed using criteria of dairy production, fat and protein contents at 100 days preceding lactation and rank of lactation. At the beginning of the experiments, the values of these criteria were as follows (1) for dairy production: 3.73 kg.day⁻¹ for C-group and 3.71 kg.day⁻¹ for S-

group, (2) for fat content: 44.7 g.kg^{-1} for C-group and 45.0 g.kg^{-1} for S-group and (3) for protein content: 32.9 g.kg^{-1} for C-group and 32.7 g.kg^{-1} for S-group. The averages per group were not significantly different.

The control and supplemented diets (C- and S-diets) were formulated to be isoenergetic and isoprotein with the same supply and nature of fibre sources. The formulation was performed per group of goats, using ALLIX² software (A Systems, France). Two types of hay were used: the first was Rye grass hay fed until 11 weeks of lactation, the second was meadow natural hay given until the end of the experiment. The difference between the two goat's diets was in the composition of the concentrates (see Table.1). The amount of concentrate was $1.2 \text{ kg.goat}^{-1}.\text{day}^{-1}$. The S-concentrate contained 2.3 % cellulose and 1.5 % more fat than the C-concentrate. The S-concentrate was supplemented with oilseeds rich in unsaturated fat (mixture of linseed oil and linseed, rapeseed and soya; the formulation of these oilseeds will not be detailed in this paper for reasons of confidentiality). The FA profile of S-concentrate was richer in C18:2n-6 (+0.3 %) and C18:3n-3 (+1.0 %) and contained lower amounts of SFA (−0.2 %), as compared with the C-concentrate. The oilseeds which were used in this study were chosen according to specific criteria of CCPA company in terms of quality of the dietary lipids: the oilseeds were rich in polyunsaturated FA, especially C18:2n-6 and C18:3n-3, and rich in free oil.

2.2 Manufacture of Camembert-type mould-ripened soft goat cheeses

Three independent camembert-type soft goats' cheese trials were performed in May and June 2009 (weeks 19, 21 and 23). The trials were performed in the INRA dairy platform (UMR STLO, 35042 Rennes, France). The protocol of manufacture was as follows:

2.2.1 Day D-1

For C-whole milks and S-whole milks, a mixture of evening milks (D-2; 5 to 6.30 pm; storage overnight at 4 °C) and morning milks (D-1; 6.30 to 8 am) were transported to the laboratory at 4 °C. Following pasteurisation at 74 °C for 20 s, the C- and S- whole milks were inoculated ($5 \text{ d.c.u.100 kg}^{-1}$) with mesophilic starters MM 100 (Danisco, 86220 Dangé Saint Romain, France): *Lactococcus lactis* subsp. *lactis*, *cremoris* and *lactis biovar diacetylactis* and ripening flora (Danisco, 86220 Dangé Saint Romain, France): *Geotrichum candidum* GEO 17 (2 doses. $1,000 \text{ kg}^{-1}$), *Penicillium camemberti* Neige (5 doses. $1,000 \text{ kg}^{-1}$) and *Kluyveromyces lactis* 71 (2 doses. $1,000 \text{ kg}^{-1}$). Twenty-five grammes of glucono delta lactone (Chr. Hansen, 91292 Saint-Germain Les Arpajon, France) were added per 50 kg of milk. For each cheese trial, 50 kg of milk were maintained in vats at 12 °C for 18 h

2.2.2 Day D

The C- and S-milks were heated to 34.5 °C and acidified to a pH of 6.10. After transferring into a 50-kg cheese vat, the addition of rennet was performed at 34 °C using 0.16 mL.kg^{-1} of rennet Maxiren 180 (DSM Food specialties, 59113 Seclin, France). The setting time was within the range of 6 to 7 min in the cheesehall maintained at 28 °C. The curd was cut after four setting times into $1.5 \times 17 \times 1.7 \text{ cm}$

Table 1 Composition of the concentrates given to the two groups of goats (control and supplemented diets; 1.2 kg of concentrate·goat⁻¹·day⁻¹)

	Concentrates composition (g.100 g ⁻¹)							Fatty acids (g.100 g ⁻¹ of fat)							
	Humidity	Cellulose	Minerals	Proteins	Starch	Fat	SFA	UFA	C18:2n-6	C18:3n-3	C16:0	C18:0	C18:1n-9	C18:2n-6	C18:3n-3
Control group	11.6	13.0	6.5	18.7	11.5	5.9	1.5	4.2	1.6	1.4	27.3	3.0	30.0	19.6	3.1
Supplemented group	10.9	14.8	6.7	19.0	10.0	7.4	1.3	5.8	1.9	2.4	9.8	2.4	29.1	26.6	20.9

Feed formulas were considered as isoenergetic and isoprotein. Each group was composed of 30 dairy Alpine goats
SFA saturated fatty acids, *UFA* unsaturated fatty acids

cubes. A portion of whey (20 % of total cheese milk weight) was drawn off 25 min after cutting the curd and then gentle stirring was applied before moulding into 11 cm diameter moulds. The cheeses were turned at the following times after moulding and decreasing room temperature—45 min (23 °C), 2 h (21 °C) and 5 h (18 °C).

2.2.3 Day D+1

The C- and S-cheeses were removed from the moulds and salted in brine (350 g NaCl.L⁻¹ of water) at 12 °C for 25 min.

Ripening was performed at 12 °C and 98 % relative humidity for 10 days with one turning after 6 days. After 10 days, the C- and S-cheeses were packed in laminated paper and poplar boxes for Camembert and then stored in a cold room at 4 °C.

The results presented are the average of the three independent replicate trials for each type of milk and soft cheeses obtained from the C- and S-diets.

2.3 Biochemical and physicochemical analyses

All physicochemical analyses were performed at least twice.

2.3.1 Milk and cheese composition

DM was determined after desiccation for 7 h at 102 to 105 °C (IDF 1987). Fat content was determined using the acid butyrometric method of Van Gulik (IDF 1997). Total nitrogen (TN) content was determined by the Kjeldahl method (IDF 1993). Proteolysis was assessed by measuring soluble nitrogen at pH 4.6 (non-casein nitrogen (NCN)), and 12 % TCA-soluble nitrogen (non-protein nitrogen (NPN)) as described previously (Gripon et al. 1975). The protein contents were calculated as TN-NPN, soluble protein by NCN-NPN and casein by TN-NCN. To quantify the evolution of proteolysis, the ratios NPN/TN and (NCN-NPN)/TN, expressed as a percentage of the cheese TN content were calculated. Total calcium concentration was determined by atomic absorption spectrometry (Varian AA 300 equipment; 91940 Les Ulis, France) as described previously (Brulé et al. 1974). The pH was measured twice, using a penetrating electrode (Ingold) linked to a Hanna pH-meter Hi 9025 (Humeau, 44241 La Chapelle-sur-Erdre, France).

2.3.2 Cheese yield

Corrected cheese yield (Y; in kilogrammes per 100 kilogrammes of milk) on a 440 g.kg⁻¹ DM basis was calculated as reported previously (Lucey and Kelly 1994). The formula used was as follows: $Y = (DM_{\text{cheese}} - DM_{\text{whey}}) / (440 - DM_{\text{whey}}) \times 100$. Moisture content in fat-free basis (MFFB; in per cent) was calculated as follows: $MFFB = (1,000 - DM) / (1,000 - \text{fat content}) \times 100$. Fat content in dry matter (FDM; in per cent) was calculated as follows: $FDM = (\text{fat content} / DM) \times 100$.

2.3.3 Fatty acid profiles of milks and cheeses

FA profiles were determined on raw milks, cheeses at Day +1 and ripened cheeses at Day +30, by Deltavit laboratory (35150 Janzé, France). Milk and cheese fat were

extracted following ISO 14156 methods (ISO-IDF 2001). The FA methyl esters (FAME) were prepared by base-catalysed methanolysis of the glycerides (KOH in methanol) according to ISO 15884 methods (ISO-IDF 2002). The FAME profile was determined by gas chromatography on an Agilent gas chromatograph, model 6890 equipped with a column CP Sil 88 (100 m×0.25 mm; internal diameter, 0.2 µm film thickness; Varian SA, 91940 Les Ulis, France). The temperature program was as follows: (1) 70 °C for 4 min, followed by (2) an increase in temperature from 70 to 175 °C at 13 °C/min, (3) held at 175 °C for 27 min, followed by (4) an increase in temperature from 175 to 215 °C at 4 °C/min (5) and finally held at 215 °C for 36 min. Total analysis run time was 85 min. Identification of the individual FA was based on a comparison of the retention times with those obtained with a known profile of milk FA. This FA profile was established using gas chromatography coupled to mass spectrometry, and using external FA standards under identical conditions.

2.3.4 Free fatty acids

The free fatty acids (FFA; from C4:0 to C18:3n-3) released upon lipolysis were determined in the cheeses at Days +1 and +30. FFA were analysed by gas chromatography according to a method adapted from (De Jong C. and Badings H.T. 1990), as previously reported by Lopez et al. (Lopez et al. 2006). Briefly, FFA were isolated from total lipids using an aminopropyl column and separated on a BP21 (SGE, Ringwood, Vic., Australia) capillary column, 25 m×0.53 mm×0.5 µm film thickness, under the following conditions: on-column injection at 65 °C; carrier gas, hydrogen, 31 kPa; temperature program, heating rate, 10 °C/min from 65 up to 240 °C, maintained for 10 min, flame-ionisation detector operated at 240 °C.

2.4 Fat globule size distribution

The fat globule size distribution was determined by laser light scattering (Mastersizer 2000, Malvern Instruments, Worcestershire, UK) with two laser sources. The refractive indexes used were 1.458 and 1.460 for milk fat at 633 and 466 nm, respectively, and 1.33 for water. Samples of goats' milk (about 0.2 mL) were diluted in 100 mL of milliQ water directly in the measurement cell of the apparatus in order to reach 10 % obscuration. The casein micelles were dissociated by adding 1 mL of 35 mM EDTA/NaOH, pH 7 buffer to the samples, in the apparatus. One millilitre of sodium dodecyl sulphate (SDS, 1 %), an anion detergent, was added in order to dissociate clusters of milk fat globules. The particle size distributions parameters were calculated by the Mastersizer software. Results were expressed in modal diameter (diameter at the peak maximum of the main population (d_{mod})), volume-weighted average diameter ($d_{43} = \Sigma n_i \cdot d_i^4 / \Sigma n_i \cdot d_i^3$) and surface-weighted average diameter ($d_{32} = \Sigma n_i \cdot d_i^3 / \Sigma n_i \cdot d_i^2$) where n_i is the number of particles of diameter d_i .

2.5 Sensory evaluation of the cheeses

Sensory analyses were performed by a specialised company (Les Maisons du Goût, 35000 Rennes, France). The sensorial profile of the soft goat cheeses (1st manufacture) at Day +30 was described in duplicate by a panel of 12 trained assessors trained

to test soft ripened cheeses. The descriptive approach tested the possible organoleptic differences between the two types of soft cheeses (Control vs. Supplemented). Scores for each descriptor were performed on an intensity scale ranging from 0 (no perception of the descriptor) to 10 (very intense perception of the descriptor). Sensory descriptors were (1) aspect of the crust (i.e. colour from white to cream and thickness), (2) aspect of the curd (i.e. chalky core size and colour from white to cream), (3) odour (i.e. intensity), (4) texture in the mouth (i.e. firm, creamy, melting, sticky, from smooth to chalky and crust perception), (5) flavour (i.e. intensity, salty, acid, bitter and pungent) and (6) aroma (i.e. goat, cream, mushroom and amoniac).

To perform this sensorial evaluation, each cheese was divided in five parts. Samples were kept at 15 °C for 1.5 h before testing at 15 °C. Cheese samples were randomly coded before being presented to the panelists. Sensory analyses were performed with 1/5 of C- and S-cheeses for each member of the testing panel, in air-conditioned individual booths, with natural light. Samples were analysed in a specified order, so that half of the panel tasted the C-cheese first, and vice versa.

2.6 Statistical analysis

Milk production, milk, cheese and whey composition data, fat globule size measurements and cheese making performances were described using analyses of variance performed with the General Linear Model procedure of the StatGraphics Plus software (Statistical Graphic Corp., Englewood Cliffs, NJ, USA). The model accounted for the fixed effects of dietary treatment and time. A Fisher test was followed by a least square difference procedure to test the significance of result differences. The level of significance selected were $P < 0.05$, $P < 0.01$ and $P < 0.001$.

For the sensory evaluation of the cheeses, the data obtained were quantitative and varied between 0 and 10. The data processing was based on a test of comparison of means (Student *t* test in matched samples) which identified the significant differences between C- and S-cheeses. Sensory differences were significant between the two products when the alpha risk was lower than 5 %.

3 Results and discussion

3.1 Milk characteristics

3.1.1 Milk production and composition

The C-diet group of goats produced milk with an average of 3.87 kg.day⁻¹ compared with 4.42 kg.day⁻¹ for the supplemented (S)-diet group of goats ($P = 0.12$). The group receiving the S-diet always produced higher amounts of milk than the C-diet group of goats. However, differences were statistically significant ($P < 0.05$) only for the second sampling at 30 days of lactation. At this stage of lactation, the difference between the two groups of goats was 0.9 kg.day⁻¹ of milk produced.

The mean composition determined for specific milk constituents are detailed in Table 2. Fat, protein and calcium contents were significantly greater ($P < 0.01$) for the S- compared with the C-milks. The protein contents of the C- and S-milks were

Table 2 Physicochemical composition of the raw control and supplemented goat milks

	Raw milks		<i>P</i> value ^a	
	Control	Supplemented	Diet	Time
pH	6.71±0.06	6.72±0.02	NS	NS
DM (g.kg ⁻¹)	120.89±4.26	125.14±4.20	—***	—***
Fat (g.kg ⁻¹)	35.33±2.25	38.83±2.60	—***	—**
TN (g.kg ⁻¹)	32.99±0.25	33.50±0.41	—**	—**
NCN (g.kg ⁻¹)	7.47±0.44	7.77±0.53	NS	NS
NPN (g.kg ⁻¹)	2.66±0.26	2.66±0.29	NS	NS
CN (g.kg ⁻¹)	25.52±0.39	25.73±0.73	NS	NS
TN-NPN=protein (g.kg ⁻¹)	30.33±0.25	30.84±0.52	—**	—**
NCN-NPN (g.kg ⁻¹)	4.81±0.21	5.11±0.26	NS	NS
Fat/CN (%; w/w)	1.38±0.01	1.51±0.01	—***	—***
Fat/protein (%; w/w)	1.16±0.07	1.26±0.07	—***	—***
Calcium (g.kg ⁻¹)	1.20±0.06	1.23±0.06	—***	—***

Mean±standard deviation (*n*=3 independent milks)

DM dry matter, TN total nitrogen, NCN non-casein nitrogen, NPN non-protein nitrogen, CN casein, TN-NPN protein, NCN-NPN soluble protein

****P*<0.001; ***P*<0.01; NS not significantly different

^a Results of the analysis of variance: probability of *F* test

slightly lower than the values reported by Raynal-Ljutovac et al. (3.2 %, w/w) (Raynal-Ljutovac et al. 2008). S-milks did not contain significantly more soluble proteins (+0.30 g.kg⁻¹; *P*=0.10) and caseins (+0.21 g.kg⁻¹; *P*=0.43) in comparison to the C-milks (Table 2). Total protein and casein contents of goat's milk depends on the genetic polymorphism of α s1 casein. The casein contents in the S- and C-milks (i.e. 25.5 and 25.7 g.kg⁻¹, respectively) are in agreement with a mixture of strong and medium polymorphism of the selected goat herds (Remeuf 1993). As goat milks are rarely standardised for fat content for cheese making, the contents in milk fat and proteins are highly important for the cheese yield. In particular, the protein content is an essential technological milk component for making cheese. Among proteins, caseins are essential for cheese making because they are retained in the cheese matrix while a portion of the soluble proteins (calculated as NCN-NPN) are lost in the whey. Low contents in total casein and total protein contents such as those reported for milks from animal with low alleles FF (about 22 and 27 g.L⁻¹, respectively, Grosclaude and Martin 1997) are not adapted to the manufacture of cheeses. This is the reason why selected strong and medium α s1 casein alleles were selected in French goat herds, such as for the studied herd.

3.1.2 Goats' milk fat globule size distribution

The size distribution of goats' milk fat globules was characterised in the raw C- and S-milks and in the corresponding pasteurised milks (Table 3). C- and S-milks had similar monomodal size distributions ranging from 0.4 to 11.2 μ m, with a majority of

Table 3 Effect of dietary polyunsaturated fat supplementation on goat milk fat globule size before and after pasteurisation

Size distribution parameters	Samples ^a				P value ^b		
	Raw C-milk	Raw S-milk	Pasteurised C-milk	Pasteurised S-milk	TT	Diet	Time
d_{mod}	3.99±0.20	4.15±0.15	3.96±0.21	4.07±0.10	NS	NS	—*
d_{43}	4.25±0.18	4.42±0.04	4.22±0.18	4.34±0.06	NS	NS	NS
d_{32}	3.38±0.02	3.46±0.10	3.38±0.03	3.47±0.09	NS	NS	NS

C control diet, S supplemented diet with polyunsaturated fatty acids, d_{mod} modal diameter of the particles, d_{43} volume mean diameter of the particles, d_{32} surface mean diameter of the particles, TT thermal treatment of pasteurisation

* $P<0.05$; NS non-significant difference

^a Mean±standard deviation ($n=3$ independent milks)

^b Results of the analysis of variance—probability of F test

fat globules having a diameter centred on 4 μm . There were no significant differences observed due to the diet, nor to the pasteurisation on the modal diameter ($P=0.11$), and the mean diameters d_{43} ($P=0.08$) and d_{32} ($P=0.09$). The goats' milk fat globule size distributions characterised in this study were larger than the values reported by Attaie and Richter (from 0.73 to 8.58 μm) (Attaie and Richter 2000). These authors also reported an average diameter of fat globules based on volume to surface area $d_{32}=2.76$ μm , which is smaller than the values found in this study (3.38 μm for C-milk and 3.46 μm for S-milk). These differences could be explained by the fact that Attaie and Richter used morning milks, instead of mixtures of evening and morning milks as were used in this study. Also, variability in the size of goat milk fat globules according to genetic polymorphism such as the $\alpha\text{s}1$ -casein variant has been reported (Neveu et al. 2002). Attaie and Richter previously reported that goats' milk contains a higher proportion of small fat globules in comparison to cows' milk: 90 % of fat globules are less than 5.1 μm in goats' milk vs. 6.4 μm in cows' milk (Attaie and Richter 2000). This could explain that goats' milk fat digestibility tends to be higher than that of cows' milk. Regarding cheese technology, it has previously been reported that small native fat globules from cows' milk affect the manufacture and sensory properties of camembert-type soft cheese as compared with the use of larger fat globules: the curd was less rigid and less firm, the cheeses were more humid (higher moisture in non fat content) and underwent a greater degree of proteolysis during ripening with a higher flowing aspect (Michalski et al. 2003). However, the effect of goats' milk fat globule size on cheese manufacture and physicochemical properties remains to be investigated.

3.1.3 FA composition of the milks

The FA compositions of the milks were significantly affected by the goats' diet (Table 4). The S-diet led to a significant decrease in SFA content from about 66 to about 60 % of total FA ($P<0.001$; Table 4). The short chain FA (C4:0 and C6:0) were not affected by diet. The amounts of C8:0, C10:0, C12:0, C14:0 and C16:0 were

Table 4 Effect of dietary polyunsaturated fat supplementation on the fatty acid profile (in grammes per 100 grammes of total fatty acid methyl esters) of goat milk and cheese after 1 and 30 days of ripening

Fatty acids	Milk		Cheese at Day +1		Cheese at Day +30		P value ^a
	Control	Supplemented	Control	Supplemented	Control	Supplemented	
C4:0	1.66±0.05	1.66±0.10	1.65±0.03	1.61±0.05	1.63±0.03	1.67±0.03	NS
C6:0	1.99±0.01	1.95±0.11	1.98±0.02	1.93±0.08	1.96±0.03	1.94±0.09	NS
C8:0	2.51±0.06	2.43±0.15	2.49±0.06	2.41±0.14	2.47±0.10	2.42±0.15	*
C10:0	8.30±0.42	7.60±0.54	8.27±0.41	7.57±0.57	8.18±0.63	7.64±0.58	****
C10:1	0.23±0.03	0.20±0.02	0.23±0.03	0.20±0.03	0.23±0.03	0.20±0.02	****
C12:0	4.25±0.31	3.47±0.17	4.25±0.30	3.47±0.23	4.27±0.32	3.51±0.24	****
C13:0	0.12±0.02	0.11±0.01	0.12±0.02	0.11±0.01	0.12±0.02	0.11±0.01	****
C14:0	8.93±0.47	7.74±0.34	8.94±0.44	7.65±0.30	8.82±0.65	7.69±0.29	****
iC15:0	0.18±0.02	0.15±0.02	0.18±0.02	0.16±0.01	0.18±0.01	0.16±0.01	*
aC15:0	0.30±0.02	0.29±0.02	0.30±0.02	0.28±0.02	0.29±0.02	0.29±0.01	****
C15:0	0.77±0.06	0.71±0.06	0.77±0.02	0.73±0.03	0.82±0.06	0.74±0.03	*
iC16:0	0.25±0.01	0.23±0.01	0.25±0.01	0.23±0.02	0.26±0.01	0.23±0.01	****
C16:0	23.89±0.69	19.13±0.64	23.92±0.45	18.91±0.65	23.93±0.49	19.02±0.64	NS
C16:1 n9	0.27±0.03	0.26±0.02	0.27±0.02	0.26±0.04	0.27±0.02	0.26±0.01	NS
C16:1 n7	0.52±0.10	0.38±0.08	0.50±0.10	0.38±0.06	0.52±0.08	0.38±0.09	****
iC17:0	0.38±0.02	0.36±0.02	0.37±0.02	0.33±0.02	0.37±0.02	0.33±0.02	NS
aC17:0	0.44±0.01	0.41±0.01	0.43±0.02	0.40±0.05	0.43±0.02	0.39±0.02	*
C17:0	0.55±0.07	0.50±0.06	0.55±0.06	0.51±0.03	0.56±0.01	0.48±0.03	****
C17:1	0.29±0.06	0.25±0.05	0.30±0.07	0.23±0.05	0.31±0.06	0.23±0.05	****
C18:0	11.06±0.22	13.15±0.56	11.11±0.31	13.20±0.32	11.12±0.39	13.15±0.37	****
C18:1 6-8t	0.36±0.01	0.51±0.06	0.38±0.04	0.48±0.07	0.35±0.00	0.46±0.03	NS

Table 4 (continued)

Fatty acids	Milk		Cheese at Day +1		Cheese at Day +30		P value ^a	
	Control	Supplemented	Control	Supplemented	Control	Supplemented	Diet	Time
C18:1 9t	0.38±0.06	0.43±0.06	0.42±0.08	0.47±0.03	0.38±0.05	0.43±0.03	NS	NS
C18:1 10t	0.61±0.06	0.78±0.23	0.55±0.05	0.76±0.18	0.56±0.08	0.77±0.12	—**	NS
C18:1 11t	1.61±0.07	3.33±0.54	1.76±0.09	3.40±0.51	1.73±0.16	3.35±0.51	—***	—***
C18:1 12t	0.45±0.04	0.76±0.09	0.51±0.10	0.72±0.10	0.50±0.03	0.72±0.11	—***	NS
C18:1 n-9c	19.90±1.34	19.88±1.67	19.70±0.80	20.22±1.55	19.77±1.39	20.14±1.51	NS	—***
C18:1 11c	0.69±0.06	0.63±0.02	0.68±0.04	0.62±0.02	0.67±0.06	0.63±0.03	—**	—**
C18:1 12c	0.38±0.03	0.58±0.04	0.36±0.07	0.60±0.03	0.39±0.01	0.59±0.03	—***	—**
C18:1:14c	0.33±0.02	0.53±0.06	0.36±0.01	0.55±0.07	0.36±0.01	0.55±0.06	—***	—**
C18:1:16c	0.12±0.02	0.16±0.03	0.11±0.00	0.16±0.01	0.12±0.02	0.15±0.01	—***	NS
C18:2:n-6c (LA)	3.14±0.09	3.21±0.13	3.13±0.07	3.23±0.18	3.15±0.06	3.13±0.04	NS	NS
C18:2:n-6t	0.29±0.02	0.49±0.06	0.28±0.03	0.50±0.05	0.30±0.04	0.51±0.09	—***	—***
C18:2 trans	0.10±0.00	0.27±0.12	0.15±0.07	0.23±0.06	0.15±0.07	0.27±0.06	—***	NS
C18:2 c9t11 (RA)	0.75±0.01	1.27±0.16	0.76±0.02	1.24±0.16	0.76±0.02	1.25±0.14	—***	—**
C18:3:n-3 (ALA)	0.78±0.09	1.78±0.24	0.77±0.09	1.78±0.20	0.80±0.12	1.74±0.37	—***	—***
C19:0	0.22±0.02	0.36±0.04	0.23±0.04	0.38±0.05	0.25±0.02	0.41±0.06	—***	—*
C19:1	0.14±0.03	0.59±0.09	0.16±0.01	0.58±0.11	0.15±0.04	0.56±0.12	—***	—***
C20:0	0.18±0.01	0.18±0.01	0.18±0.01	0.18±0.01	0.18±0.01	0.18±0.01	NS	—**
C20:4:n-6	0.14±0.01	0.11±0.01	0.15±0.01	0.11±0.00	0.15±0.01	0.12±0.02	—**	NS
SFA	65.98±1.39	60.43±0.56	66.00±1.20	60.08±0.73	65.84±1.65	60.36±0.72	—***	—***
UFA	31.60±1.44	36.51±0.69	31.63±1.12	36.82±0.84	31.74±1.46	36.54±0.62	—***	—***
MUFA	26.40±1.45	29.28±1.06	26.38±1.23	29.61±0.91	26.43±1.59	29.42±1.05	—***	—***
PUFA	5.20±0.03	7.23±0.41	5.24±0.15	7.21±0.43	5.31±0.18	7.12±0.68	—***	—**

Table 4 (continued)

Fatty acids	Milk		Cheese at Day +1		Cheese at Day +30		P value ^a	
	Control	Supplemented	Control	Supplemented	Control	Supplemented	Diet	Time
CLA	0.75±0.01	1.27±0.16	0.76±0.02	1.24±0.16	0.76±0.02	1.25±0.14	—***	—**
n-3	0.78±0.09	1.89±0.25	0.77±0.09	1.89±0.21	0.80±0.12	1.85±0.37	—***	—***
n-6	3.57±0.08	3.81±0.10	3.56±0.05	3.84±0.21	3.59±0.04	3.76±0.12	—***	NS
Total <i>trans</i> -FA	3.81±0.14	6.57±0.68	4.04±0.28	6.56±0.66	3.97±0.39	6.51±0.68	—***	—**
LA/ALA	4.04±0.55	1.80±0.34	4.05±0.59	1.81±0.30	3.92±0.71	1.80±0.42	—***	—***
n-6/n-3	4.59±0.61	2.02±0.33	4.60±0.62	2.03±0.30	4.47±0.77	2.04±0.40	—***	—***
C18:1/C16:0	1.04±0.08	1.44±0.03	1.04±0.06	1.48±0.00	1.04±0.08	1.46±0.01	—***	—*

Mean±standard deviation (n=3)

SEA saturated fatty acids, UFA unsaturated fatty acids, MUFA monounsaturated fatty acids, PUFA polyunsaturated fatty acids, R4 rumenic acid (main conjugated linoleic acids (CLA)), ALA alpha-linolenic acid, LA linoleic acid

*P<0.05; **P<0.01; ***P<0.001; NS non-significant difference

^a Results of the analysis of variance—probability of F test

significantly ($P<0.01$) decreased to between 15 and 26 % in the S-milks in comparison to C-milks. It is interesting to note that the PUFA dietary supplementation performed in the S-diet reduced the index of atherogenicity of goats' milk fat with the decrease in C12:0, C14:0 and C16:0, as already reported in literature for other UFA-enriched goat diets (Hu et al. 2001). Among the SFA, C18:0 was increased from about 11 % of total FA in the C-diet up to 13 % of total FA in the S-diet. This is due to the hydrogenation of the C18 unsaturated FA in the goats' rumen (Chilliard et al. 2006). Feeding supplementation with PUFA also diminished ($P<0.01$) the percentage of the odd-chain FA (C13:0, C15:0 and C17:0) and most of the branched-chain FA (C15:0 *iso*, C15:0 *anteiso*, C16:0 *iso*, C17:0 *iso* and C17:0 *anteiso*) in goats' milk fat. The S-diet significantly increased the total unsaturated FA from 31.6 % up to 36.6 % of total FA ($P<0.001$; Table 4). The proportion of monounsaturated FA was significantly increased from 26.4 % with the C-diet, up to 29.4 % of total FA with the S-diet ($P<0.001$; Table 4). The amount of oleic acid C18:1n-9 was not affected by dietary PUFA supplementation but the C18:1 *trans*-FA were significantly ($P<0.001$) increased in the S-milks, except the C18:1 9t. The vaccenic acid C18:1 11t increased from 1.7 % in the C-diet up to 3.4 % of total FA in the S-diet, as previously reported for supplementation of PUFA-rich lipids in the diet (Sanz Sampelayo et al. 2007). The C18:1 *trans*-FA originate from the ruminal bio-hydrogenation of PUFA from the forages and concentrates (Chilliard et al. 2003). The PUFA were positively affected by fat intake supplementation ($P<0.001$) with an increase from about 5.2 to 7.2 % of total FA (1.4-fold). The linoleic acid C18:2n-6 was not affected by S-diet. The rumenic acid C18:2 9c11t (main CLA) was significantly increased from about 0.8 to 1.3 % of total FA ($P<0.001$). Rumenic acid C18:2 9c11t is synthesised by isomerisation of the linoleic acid C18:2n-6 in the rumen and by action of the delta 9 desaturase on the vaccenic acid in the mammary gland (Chilliard et al. 2003; Sanz Sampelayo et al. 2007). A strong linear correlation between goats' milk C18:2 9c11t and C18:1 11t has previously been reported in literature (Chilliard et al. 2003). The linolenic acid C18:3n-3 was significantly increased from about 0.8 to 1.8 % of total FA ($P<0.001$; Table 4). Such increase in the C18:3n-3 content has previously been reported in the milk of goats' fed diets containing linseed oil and linseeds, which are rich in C18:3n-3 (Chilliard and Ferlay 2004). Hence, the PUFA supplemented diet used in this study was efficient in increasing the PUFA content in goat's milk. The n-6/n-3 FA ratio was decreased by 2.57 % in the S-milk ($P<0.001$). These results, showing the increase in PUFA in goat's milk due to a PUFA-rich diet, are in agreement with previous works reported in literature (Chilliard et al. 2005, 2006; Sanz Sampelayo et al. 2007).

3.2 Manufacture and cheese physicochemical characterisation

3.2.1 Cheese and whey composition

The mean values for the selected cheese and whey constituents are detailed in Table 5. The DM and fat contents were within the range for goats' soft cheese composition (Gaborit et al. 2001; Raynal-Ljutovac et al. 2008). Cheese fat and FDM were significantly higher ($P<0.01$) in the S- than C-cheeses. These differences were related to a significant higher fat to protein ratio in the S- compared with C-milks (+8.6 %; $P<0.001$) and the absence of fat standardisation before cheese making.

Table 5 Physicochemical compositions of the cheese and whey after 1 day

	Goat diet		<i>P</i> value ^a	
	Control	Supplemented	Diet	Time
Cheese at Day +1				
pH	4.52±0.02	4.56±0.03	NS	NS
DM (g.kg ⁻¹)	443.17±1.73	453.95±5.99	—***	NS
Fat (g.kg ⁻¹)	232.50±8.22	247.50±4.18	—***	—*
FDM (% <i>, w/w</i>)	52.46±1.74	54.53±1.04	—**	—*
TN (g.kg ⁻¹)	175.12±6.07	171.35±6.16	—*	—***
NCN (g.kg ⁻¹)	12.37±1.08	11.97±0.65	NS	—*
NPN (g.kg ⁻¹)	6.45±0.23	6.31±0.31	NS	NS
CN (g.kg ⁻¹)	162.75±5.13	159.39±5.75	—*	—***
TN-NPN=protein (g.kg ⁻¹)	168.67±6.05	165.04±5.95	—*	—***
NCN-NPN (g.kg ⁻¹)	5.91±1.03	5.66±0.41	NS	—**
NPN/TN (% <i>, w/w</i>)	3.69±0.17	3.68±0.13	NS	NS
(NCN-NPN)/TN (% <i>, w/w</i>)	3.36±0.48	3.30±0.21	NS	—*
Calcium (g.kg ⁻¹)	3.08±0.08	2.84±0.04	—***	—*
Calcium/FFDM (% <i>, w/w</i>)	1.46±0.08	1.37±0.03	—*	NS
MFFB (% <i>, w/w</i>)	72.56±0.67	72.57±0.81	NS	—*
Whey				
DM (g.kg ⁻¹)	63.83±0.94	64.67±0.87	—***	—***
Fat (g.kg ⁻¹)	1.25±0.39	1.33±0.38	NS	—***
TN (g.kg ⁻¹)	8.75±0.09	8.89±0.15	—**	—**
NCN (g.kg ⁻¹)	8.49±0.41	8.56±0.46	NS	NS
NPN (g.kg ⁻¹)	4.05±0.26	4.04±0.31	NS	NS
CN (g.kg ⁻¹)	0.26±0.36	0.33±0.44	NS	NS
TN-NPN (g.kg ⁻¹)	4.70±0.22	4.84±0.24	—*	NS
NCN-NPN (g.kg ⁻¹)	4.44±0.43	4.52±0.44	NS	NS
Calcium (g.kg ⁻¹)	0.89±0.06	0.93±0.05	—***	—***

DM dry matter, FDM fat in dry matter, TN total nitrogen, NCN non-casein nitrogen, NPN non-protein nitrogen, CN casein, FFDM fat-free dry matter, MFFB moisture on fat free basis

P*<0.05; *P*<0.01; ****P*<0.001; NS not significantly different

^a Mean±standard deviation (*n*=3)

^b Results of the analysis of variance: probability of *F* test

After curd draining, the same amount of fat was removed in the whey for both cheeses. Enrichment of S-milk with PUFA did not result in higher fat losses in the whey in comparison to the C-milk. Fat is known to be important in allowing moisture to be retained in cheese (Lelievre 1983), which is linked to the ability of the milk fat globule membrane to bind water. The MFFB was equivalent for both the C- and S-cheeses and it allowed therefore a comparison of their enzymatic activities. The

protein content was lower in the S-cheeses in comparison to (-2.2% ; $P<0.05$) the C-cheeses. Indeed, the S-whey had a significantly higher protein content than the C-whey ($+3.0\%$; $P<0.05$). In addition, C-cheeses contained significantly more calcium than the S-cheeses ($+8.5\%$; $P<0.01$). This higher mineralisation could be explained by a higher pH for the C-curd during draining (Fig. 1). Despite having a similar pH at the renneting ($P=0.376$) and demoulding steps ($P=0.215$), the pH of C-curd tended to be higher between the moulding stage ($P=0.157$) and the second turn ($P=0.120$). In comparison to Rocamadour cheese ($0.71\text{--}1.73\text{ g.kg}^{-1}$) (Lucas et al. 2008), the calcium content of the C and S-cheeses characterised in this study were higher.

3.2.2 Cheese-making parameters and yield

The PUFA supplementation of the goats' diet did not affect the technological processes such as whey drainage kinetics and curd pH decrease (Fig. 1).

Corrected cheese yields were $15.4\pm0.7\%$ for C-cheeses vs. $16.3\pm0.5\%$ for the S-cheeses. The S-cheeses yields were 5.7% higher ($P<0.05$) than the C-cheeses yields. The calculation of the corrected outputs was measured and adjusted to 66% moisture content. The cheese yields were affected by the type of goats' diet and the resulting milk composition. DM content is the strongest predictor among the major milk components for goats' cheese yield capacity. It is correlated to the contents of casein and fat in the milk (Guo et al. 2004). The retention of milk DM in the C-cheeses ($56.1\%\pm0.7$) was similar to the S-cheeses ($57.0\%\pm1.3$). The yield increase characterised for the S-cheeses was mainly due to a higher fat content in the S-milks than in the C-milks. These results are in agreement with literature: it has previously been reported that lipid supplementation did not alter the cheese-making ability but

Fig. 1 Evolution of cheese-making parameters: (1) pH of control milk and curd (empty circles) and supplemented milk and curd (filled circles), (2) draining of control curd (empty triangles) and supplemented curd (filled triangles) and (3) temperature of control curd (empty squares) and supplemented curd (filled squares). Bars represent the standard deviation. Draining of curd values, pH and temperatures of the curd were not significantly different ($P>0.05$) between the control and the supplemented cheeses

improved the cheese yield and fat recovery ratio due to a higher milk fat content (Chilliard et al. 2006).

3.2.3 FA profiles of the cheeses

There were no differences in the FA profiles between milks and cheeses produced at Day +1 or after ripening at Day +30 (Table 4). The different steps involved in the manufacture and ripening of Camembert-type cheeses did not affect the FA compositions. Such results are in agreement with previous studies reported for different kinds of cheeses produced from goats' milk (Chilliard et al. 2006) and cows' milk (Briard-Bion et al. 2008). In comparison to previous findings, even the C-cheese SFA content was lower than that previously reported for other goats' cheese types, e.g. Rocamadour-type cheeses (from 70.8 to 74.1 %) (Lucas et al. 2008).

3.2.4 Proteolysis and pH evolution during cheese ripening

Throughout the entire ripening period, the peptide and amino acid contents (NPN / TN) as well as the soluble proteins content ((NCN-NPN)/TN) were similar between the S-cheeses and the C-cheeses (Fig. 2). Hence, proteolysis was not affected by the diet of the goats. pH evolution during cheese ripening mainly depends on the choice of the ripening strains, as previously reported (Gaborit et al. 2001). During ripening, the pH increased from 4.5–4.6 to 5.8–5.9 for both types of cheese. The ripening reactions induced the conversion of lactic acid into lactate and the release of NH_3 by proteolysis, leading to an increase in the pH. Gaborit et al. reported similar pH evolution during ripening, for lactic cheeses prepared from goats' milk (Gaborit et al. 2001).

Fig. 2 Evolution of pH and proteolysis of cheeses during ripening: peptides and free-amino acids (NPN/TN) and soluble proteins ((NCN-NPN)/TN). Bars represent the standard deviation. NPN/TN, (NCN-NPN)/TN and pH values were not significantly different ($P > 0.05$) between the control and the supplemented cheeses

3.2.5 Lipolysis during cheese ripening

The amount of FFA released during ripening was similar in the S- and C-cheeses. This level increased from 0.2 ± 0.1 g/100 g fat at Day +1 up to 9.3 ± 0.8 g/100 g fat and 7.8 ± 1.5 g/100 g fat at Day +30 for the C-cheeses and the S-cheeses, respectively (Fig. 3). The low levels of FFA detected in the cheeses at Day +1 may originate (1) from an initial lipolysis (spontaneous lipolysis) in the raw goats' milk, (2) from milking practices and storage conditions before cheese making and/or (3) to the enzymes of the mesophilic starters. Indeed, milk pasteurisation inactivated the endogenous enzymes, and the ripening flora did not grow at this early stage of cheese ripening (Collins et al. 2003; Gaborit et al. 2001). Thus, the high increase in the level of lipolysis observed during the ripening period (Table 3) probably resulted from the hydrolytic action of the enzymes of the yeasts and moulds found mainly at the cheese surface, as suggested previously (Collins et al. 2003; Gaborit et al. 2001). The extent of lipolysis was not significantly different between the S-cheeses and the C-cheeses ($P > 0.05$), indicating that the PUFA rich goat's diet and consequently the milk composition did not affect the mechanisms of fat hydrolysis that occurred during ripening. Although limited data are available regarding the levels of lipolysis during mould-ripened soft goat cheese ripening, our results are in agreement with the literature. Previous authors have reported levels up to 6 % lipolysis at Day +31 of ripening for Sainte Maure goats' cheese (soft cheese with a mould-ripened surface) (Le Quéré et al. 1998). Depending on the ripening strains used, previous authors have reported levels ranging from 2.7 to 6.4 % lipolysis in Camembert-type cheeses prepared from goats' milk (Gaborit et al. 2001). Gripon reported levels of 6 to 10 % lipolysis in Camembert cheeses made from cows' milk (Gripon 1993).

With regard to the structure of the individual FFA (chain length and degree of unsaturation) released during ripening, it was similar in the C- and S-cheeses at Day +1 with a profile dominated by C16:0, C18:1 9c and C18:0 which accounted for 72.2 ± 5.7 % of total FFA (Fig. 4a). Thus, the medium-chain length FFA C10:0, C12:0 and C14:0 and the PUFA C18:2n-6 were the most released (Fig. 4a). At Day +30 of ripening, the main FFA released were C18:1 9c and C16:0 which accounted for 52.5 ± 1.0 % of total FFA (Fig. 4b). For both C- and S-cheeses, the FFA fraction was slightly

Fig. 3 Levels of lipolysis expressed in grammes of free-fatty acids (FFA) per 100 grammes of fat detected at Days +1 and +30 during ripening of goat cheeses manufactured with milk produced with the control diet (C) or the supplemented diet (S). Bars represent the standard deviation. Whatever the time of ripening, the levels of lipolysis were not significantly different (NS; $P > 0.05$) between the control cheeses and the supplemented cheeses

Fig. 4 Concentration of individual free fatty acids (FFA) expressed in grammes per 100 grammes of FFA, released during ripening of control and supplemented goat cheese **a** at Day +1 and **b** after ripening at Day +30. Bars represent the standard deviation. Means with different letters (*a* and *b*) are significantly different at $P<0.05$

enriched in *cis*-UFA as compared with the esterified fraction (total FA) after 30 days ripening: *cis*-UFA represented 31.7–36.5 % of total FA and 38.8–41.9 % of FFA. These results were related to the *G. candidum* lipase which possesses a high specific activity for long-chain FA moieties containing a *cis*-double bond at the n-9 position, particularly C18:1 9c (Greyt and Huyghebaert 1995). As for the total FA profile of the cheeses, C10:0, C12:0 and C14:0 were the most abundant FFA among the short- and medium-chain FFA (i.e. from C4:0 to C14:0) that were released during lipolysis. Differences in the individual FFA profiles were detected between the C- and S-cheeses after 30 days of ripening (Fig. 4b). The short-chain FFA (i.e. C4:0–C9:0) and the medium-chain FFA (i.e. C10:0–C14:0) were significantly lower ($P<0.05$) in the S-cheeses in comparison to the C-cheeses (6.2 ± 0.7 vs. 8.3 ± 0.2 % and 24.2 ± 0.3 vs. 26.5 ± 0.2 %, respectively). C16:0 was also significantly ($P<0.05$) lower in the S-cheese in comparison to the C-cheese. The saturated FFA C18:0 and unsaturated FFA C18:1 9c were significantly higher in the S-cheeses as compared with C-cheeses. These differences in the FFA profile characterised at Day +30 of ripening reflect the differences detected in the milks produced from the different goats' diets. Since fat contributes to flavour directly via lipolysis (particularly the short-chain FFA; (Collins et al. 2003), these differences in the FFA profiles could have an impact on the cheeses flavour. Indeed, the characteristic aromatic notes providing specific and typical goat flavour originate from FFA such as C6:0, C8:0, C9:0, C10:0 and from the branched-chain FA 4-ethyl-C8:0 and 4-methyl-C8:0 that are perceived even at very low concentrations and are generally present at levels higher than their perception threshold, as discussed by Gaborit et al. (2001). The FFA released during lipolysis also act as precursor molecules for a series of catabolic reactions leading to the production of flavour compounds, such as methyl ketones, lactones, esters, alkanes and secondary alcohols (Collins et al. 2003).

3.2.6 Cheese sensory quality

The sensory profiles obtained were similar for both types of cheese (Fig. 5). The only significant differences detected were in the perception in mouth of the crust and notable differences of the goats' cheese flavour. Indeed, the S-cheeses presented a lesser significant perceptible crust than the C-cheeses ($P=0.046$). The average score for the S-cheese was 4.9 vs. 5.9 out of 10 for the C-cheese. This difference was not considered as a crust defect for the C-cheeses. The FDM of the S-cheeses was higher than the C-cheese (2.1 %, $P<0.01$) (Table 5). This difference in fat content tended to enhance a creamier ($P=0.80$) and a smoother texture ($P=0.42$) for the S-cheeses (Fig. 5). Those sensory distinctions may have masked the perception of the crust in the mouth of the S-cheeses compared with the C-cheeses.

The goats' cheese flavour tended to be less intense for the S-cheeses compared with the C-cheeses ($P=0.073$). The characteristic flavour of goats' cheese is particularly affected by its content in short chain FFA (C6:0–C10:0), which was lower in the S-cheeses than in the C-cheeses after 30 days of ripening (Fig. 4). This observation was related to the cheese FA profile which revealed a decrease in the caprylic and capric acid content (specific FA of the goat's milk) as a result of the diet supplementation in PUFA (Table 4). According to the literature, the reduction in goats' cheese flavour has been explained by a reduction in the level of lipolysis in milks when animals

Fig. 5 Sensorial profile of the soft goat cheeses prepared with control goat milk and supplemented goat milk. The arrow shows significantly different characteristic ($P < 0.05$, Student t test). Bars represent the standard deviation

receive a diet supplemented with vegetable oil (Chilliard et al. 2003). However, the lipolysis levels found in this study were similar between the S- and C-cheeses at D+1 and were in agreement with literature at Day +30 of ripening and not significantly different between the S- and C-cheeses, as already discussed. Despite the finding of a less intense goats' cheese flavour, the average value for this descriptor was 5.2 out of 10. The goats' cheese flavour was considered as correct and still present.

Furthermore, no differences in bitter taste or pungent sensation were noted between the C- and S-cheeses. No defects of oxidised or rancid (excessive release of butyric acid) flavours were detected. Hence, the PUFA supplementation that has been performed through the addition of C18:2n-6 (19.2 and 22.8 g.goat⁻¹.day⁻¹ for C- and S-diets, respectively) and C18:3n-3 (16.8 and 28.8 g.goat⁻¹.day⁻¹ for C- and S-diets, respectively) in goat's diet (Table 1), which has led to a significant increase in PUFA in the S-milks and S-cheeses (Table 4), did not negatively affect the sensorial properties of the cheeses. This is a positive point for the dairy industry that fears the oxidation of the cheeses following the incorporation of PUFA in the diet of the animals.

4 Conclusions

Composition of goat milk can be improved by feeding a diet supplemented with high level of PUFA-rich fat (69.6 g UFA.goat⁻¹.day⁻¹; 28.8 g C18:3n-3.goat⁻¹.day⁻¹) if the levels of energy and protein in the diets are sufficient. Modulation of the FA composition of goats' cheese can be achieved through feeding the goats, particularly

with PUFA oilseeds. A reduction in the SFA level and an increase in the PUFA such as the C18:3n-3 (from 0.8 up to 1.8 % of total FA), improved the nutritional quality of both the goats' milk and cheese. Thanks to the higher fat and protein contents produced in the supplemented milk, the cheese yield increased. This variation in gross composition of milk for cheese-making did not affect the processing characteristics of the milk and the sensory quality of the ripened cheeses. The sensorial properties of goats' cheeses were not affected by this PUFA supplementation.

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