Lactation Response and Nitrogen, Calcium, and Phosphorus Utilization of Dairy Goats Differing by the Genotype for α_{S1} -Casein in Milk, and Fed Diets Varying in Crude Protein Concentration

Ph. Schmidely, F. Meschy, J. Tessier, and D. Sauvant

Unité Mixte de Recherches "Physiologie de la Nutrition et Alimentation",
Département des Sciences Animales
Institut National Agronomique,
Paris-Grignon, France

ABSTRACT

Twenty-four dairy goats were used in a preliminary trial to evaluate the effect of the genotype for α_{S1} -casein (α_{S1} -CN) in milk [homozygous variant A/A ($n = 12$) or F/F ($n = 12$)] on milk yield and composition for 2 wk from kidding. After this period, the main trial aimed at determining the effects of the genotype for α_{S1} -CN in milk, the dietary crude protein concentration on milk yield and composition, and utilization of N, Ca and P. The goats within each genotype were allocated to a 3×3 Latin square for 14 wk with three crude protein concentrations in the total mixed ration (13.2, 16.8, and 19.8% of dry matter) and three periods (wk 3 to 6, wk 8 to 11, and wk 13 to 16 postpartum) as factors. Balances of N, Ca, and P were determined in the last week of each period. Two wk after kidding, the α_{S1} -CN A/A goats had higher percentage and yield of protein and lower body weight than the α_{S1} -CN F/F goats. During the main trial, yields of protein and fat, as well as percentages of fat and protein in milk were higher for the α_{S1} -CN A/A goats than for the α_{S1} -CN F/F goats, independent of dietary CP concentration and period. Efficiency of N digestion for milk N was higher for the α_{S1} -CN A/A goats than for the α_{S1} -CN F/F goats. Urinary N as a percentage of digested N, and total N excretion expressed relative to milk N were lower for the α_{S1} -CN A/A goats than for the α_{S1} -CN F/F goats. Neither the apparent absorption of calcium or phosphorus was affected by the genotype for α_{S1} -CN. Goats fed the low crude protein diet had lower milk yield and lower yields of fat and protein than those fed the other diets. Increasing dietary crude protein concentration increased urinary N, milk N, and N excretion relative to milk N; it also decreased the efficiency of digested N for milk N. In conclusion, selection of goats with a genetically higher

yield of casein and fed with diets formulated to reduce N excretion improves the cheese-making properties of goat milk and reduces concerns about N wastes in the environment.

(Key words: α_{S1} -casein, milk composition, nitrogen utilization, goat)

Abbreviation key: LPD = low-protein diet, MPD = medium-protein diet, HPD = high-protein diet, PDI = digestible protein in the intestine, RMY = raw milk yield.

INTRODUCTION

The protein composition and the renneting ability of the milk of dairy goats both influence cheese yield and quality (Brown et al., 1995). Besides the postpartum variations in the components of goat milk, genetic variations exist in the concentrations of protein and fat in milk (Barbieri et al., 1995) and in the quantity of individual CN (Grosclaude et al., 1987; Mahé and Grosclaude, 1989). High polymorphism for the locus of the α_{S1} -CN gene is associated with genetic variants of milk in Alpine and Saanen breeds. Allelic variants α_{S1} -CN^A, α_{S1} -CN^B, and α_{S1} -CN^C are associated with a high content of α_{S1} -CN (3.5 g/L), α_{S1} -CN^E with an intermediate content (1.1 g/L), α_{S1} -CN^D and α_{S1} -CN^F with a low content (0.5 g/L), while α_{S1} -CN^O is a null allele (Grosclaude et al., 1987; Mahé and Grosclaude, 1989). A similar hierarchy has been observed for the percentage of fat in milk during the entire lactation with no difference in milk yield (Mahé et al., 1993). However, these findings are based on goats whose feeding practices are unknown. Moreover, it is not known if these differences are expressed in early lactation when body reserves are mobilized or if nutrient utilization (especially N) is affected by genetic variants for α_{S1} -CN. Finally, nothing is known about the Ca and P metabolism of these goats.

In early lactation, limited DMI leads to the formulation of diets with a high CP concentration to meet the CP requirements for required protein yield. During this period, a dietary CP level below 14% (DM basis) in goats

Received December 27, 2001.

Accepted March 30, 2002.

Corresponding author: Ph. Schmidely; e-mail: schmidel@inapg.inra.fr.

and cows generally reduces milk yield (Brun-Bellut et al., 1990; Kung and Huber, 1983), with no change (Brun-Bellut et al., 1990; Kung and Huber, 1983) or a slight decrease (Ha and Kennely, 1984) in the concentration of protein in milk. Increasing dietary CP concentration above 14 to 15% results in no or diminishing returns for milk yield and concentration of protein (Kalscheur et al., 1999). Moreover, increased N excretion due to excess CP intake is partly responsible for environmental concerns about manure disposal and nitrates in ground water (Tamminga, 1992).

Consequently, the objective of this study was to determine the magnitude of the differences for DMI, milk yield, milk composition, utilization of N, Ca, and P between homozygous variants A/A and F/F for α_{S1} -CN fed 3 CP concentrations in early lactation.

MATERIALS AND METHODS

Goats and Diets

Twenty-four multiparous Alpine ($n = 14$) or Saanen ($n = 10$) dairy goats homozygous for the genotype of α_{S1} -CN in milk (genotype A/A, $n = 12$, seven Alpine and five Saanen goats; genotype F/F, $n = 12$, seven Alpine and five Saanen goats) were used for 16 wk from kidding. During a preliminary trial (2 wk from kidding) the goats were housed collectively on straw litter. During the main trial (wk 3 to 16) the goats were housed individually in 2×1 -m metabolic crates with wooden floors, and they were hand-milked twice daily (0700 and 1600 h). All goats were fed twice daily in two equal meals (0730 and 1700 h), and the goats had free access to water and to a trace-mineralized salt block during the day.

Three experimental TMR (46% of DM) were formulated to be below, at, and above requirements for digestible protein in the intestine (**PDI**; INRA, 1989) with low-protein diet (**LPD**), medium-protein diet (**MPD**), or high-protein diet (**HPD**) concentrations, respectively (Table 1). On a DM basis, they contained the following: 40% dehydrated alfalfa pellets (NDF, 400 g/kg; ADF, 300 g/kg; CP, 180 g/kg), 30% sugar beet pulp silage (NDF, 510 g/kg; ADF, 220 g/kg; CP, 100 g/kg), 1% CaCO_3 , 1% mineral premix, and 28% of a concentrate with soybean meal and barley in the proportions 0/100, 30/70, 66/34 for LPD, MPD, and HPD diets, respectively.

Experimental Design and Sampling Procedures

During the preliminary trial, the goats had free access to the MPD diet. At the end of this period, the 12 goats of each genotype for α_{S1} -CN were randomly assigned to a 3×3 Latin square design with diet and

period (stage of lactation) as factors (main trial). Periods were defined as wk 3 to 6 [period 1: increase in raw milk yield (**RMV**)], wk 8 to 11 (period 2), and wk 13 to 16 (period 3: decrease in RMV). At the end of the preliminary trial, the goats were abruptly switched from the MPD diet to their experimental diet. Weeks 7 and 12 were for the transition between diets; the goats were introduced to their new diet by mixing the old and new diets at 80 to 20 on d 1, at 60 to 40 on d 2, at 40 to 60 on d 3, at 20 to 80 on d 4, and at 0:100 on d 5.

The goats were weighed once per week, between morning milking and feed distribution. The milk yield, amount of feed distributed, and orts (except during the first 2 wk after kidding) were recorded individually each day. Once per week, individual milk samples were obtained from two consecutive a.m. and p.m. milkings and were analyzed for fat, protein, and milk fatty acid concentration.

The balances of N, Ca, and P were measured as described by Schmidely et al. (1999) on 18 goats (three goats of each genotype for each dietary treatment) for five consecutive days during the last week of each period (to ensure that the rumen was fully adapted to the diets). During these periods, representative samples of the diets and orts were collected every 2 d, and representative samples of feces were collected daily. The samples were frozen and pooled at the end of the period for analysis. Urine was collected daily, acidified (5% of urine volume) with a solution of 30% sulfuric acid in water (density = 1.72, vol/vol), stored at room temperature, and pooled at the end of the period; an aliquot of 50 ml was collected and frozen for analysis of N content. Duplicate samples (100 g) of diets, orts, and feces were used to determine water and ash content (only for diets) in duplicate. Samples of diets, orts, and feces (1 g each) and urine (5 ml) were used for determination of N content in duplicate. The N content of the milk (measured for 2 d as described previously) was calculated from its protein content.

Analytical Procedures

The water content of diets, orts, and feces was measured by 72-h freeze-drying to a constant weight. The OM content of the diets was obtained after ashing at 550°C for 12 h. The NDF and ADF concentrations in the diets were determined according to the method of Van Soest et al. (1991). The starch concentration of the diets was determined using an amyloglucosidase (reference 207748; Boehringer-Mannheim, Meylan, France). The total of N in diets, orts, feces, and urine was measured by the micro-Kjeldahl technique. Phosphorus was analyzed by the colorimetric nitro-vanado-

molybdate method, and Ca was determined by flame spectrophotometry.

Milk fat and protein were analyzed by near-infrared analysis (Milkoscan; Foss Electric, Hillerd, Denmark). Fatty acid methyl esters for milk fat analysis were prepared as described by Bas (1985). The GLC of fatty acid methyl esters was performed with a Variant 3400 (Les Ullis, France) with an inox column (3m) packed with DEGS (4%) on Chromosorb GAW – DMCS (80/100 mesh; Supelco, Bellefonte, PA). The temperature of the injector was 250°C, and that of the detector was 280°C; the column temperature programming was 85° for 1 min, increased by 3°C/min to 185°C and held for 50 min.

Statistical Analysis

Data recorded during the 2 wk after kidding were analyzed by week using the general linear model procedure of SAS (2000) with the model:

$$Y_{ij} = \mu + C_i + G(C)_{j(i)} + E_{ij}$$

where μ = overall mean, C_i = effect of genotype for α S1-CN (1df), $G(C)_{j(i)}$ = goat within gene (used as the error term to check C_i) and E_{ij} = the residual error. The data recorded during the first 3 wk of each period of the main trial were eliminated, and the data measured during the last wk of each period were analyzed with the following model:

$$Y_{ijkl} = \mu + A_i + B_j + C_k + AC_{ik} + BC_{jk} + AB_{ij} + G(C)_{l(k)} + E_{ijkl}$$

where μ = overall mean, A_i = effect of the dietary CP concentration, B_j = effect of the period, C_k = effect of genotype for α S1-CN, AC_{ik} = interaction between A_i and C_k , BC_{jk} = interaction between B_j and C_k , AB_{ij} = interaction between A_i and B_j , $G(C)_{l(k)}$ = goat within gene, and E_{ijkl} = the residual error. Goat within gene $G(C)_{l(k)}$ was used to check the effect of the genotype for α S1-CN, and root mean square error was used as the error term to check all the other effects. None of the interactions studied (AC_{ik} , BC_{jk} , AB_{ij}) was significant; these terms were dropped from the model and pooled with the residual term, and only the main effects were presented. Significance was declared at $P < 0.05$, unless otherwise stated.

RESULTS

The chemical composition of the diets is shown in Table 1. Standard deviation of CP content was 0.8, 1.1, and 1.2% CP for LPD, MPD, and HPD respectively. As expected, the LPD, MPD and HPD were below, at, and

Table 1. Composition and chemical analysis of the experimental diets.

Item	Diet		
	Low Protein (LPD)	Medium Protein (MPD)	High Protein (HPD)
Ingredient composition, % DM			
Dehydrated alfalfa pellets	40	40	40
Sugar beet pulp silage	30	30	30
Mineral ¹	1	1	1
CaCO ₃	1	1	1
Soybean meal	0	8	18
Barley	28	20	10
Chemical analysis, g/kg of DM			
Ash	80.0	82.5	86.7
CP	132.4	168.4	198.4
NDF	417.2	419.5	432.0
ADF	245	238.5	246
Lignin	42.0	37.8	39.0
Starch	165.2	120.0	104.0
Calcium	13.1	13.3	12.8
Phosphorus	4.2	4.5	4.6
NE _L , ² MJ/kg of DM	6.50	6.70	6.70
PDIN, ³ g/kg of DM	79	108	137
PDIE, ³ g/kg of DM	89	104	120
LYSdi, ⁴ % of PDIE	7.10	7.12	7.14
METdi, ⁴ % of PDIE	1.77	1.73	1.70

¹Mineral contained 30% dicalcium phosphate, 20% sodium bicarbonate, 20% trace-mineralized salt, 20% limestone, 4% CaSO₄, 4% MgO₃, 2% urea, 650,000 IU/kg of vitamin A, 350,000 IU/kg of vitamin D₃, and 4000 IU/kg of vitamin E.

²Calculated from INRA (1989).

³PDIN and PDIE = Digestible protein in the intestine when rumen fermentable N supply or energy supply are limiting, respectively (17).

⁴LYSdi, and METdi = Digestible lysine in the intestine, and digestible methionine in the intestine, respectively (INRA, 1989).

above PDI requirements, respectively (INRA, 1989). The three diets in the same order, were below, slightly above, and markedly above CP requirements of NRC (1981) for goats. Because of the substitution of barley with soybean meal, starch concentration was significantly different between the LPD, MPD, and HPD diets: 165, 120, and 104 g/kg DM (SEM = 16 g/kg DM, $P < 0.05$), respectively. The 3 diets did not differ in regard to the concentrations of NDF and ADF. The three diets were markedly above the requirements for Ca (INRA, 1989; NRC, 1981), due to the calcium-rich components (sugar beet pulp silage and dehydrated alfalfa pellets). Significant differences in P concentration between the three diets were observed—P content increased linearly (SEM = 0.40 g of P/kg of DM; $P < 0.05$) as the CP level increased because of the substitution of barley (4 g of P/kg of DM) with soybean meal (7 g of P/kg of DM). The three diets were slightly above the requirements for P (INRA, 1989; NRC, 1981).

DMI, Milk Yield and Composition

During the first week after kidding, no difference between the two genotypes was observed for RMY,

Table 2. Milk yield and composition from lactating dairy goats affected by the genotype for α_{S1} -CN in milk during wk 1 and wk 2 postpartum.¹

Genotype for α_{S1} -CN in milk	Stage of lactation							
	Wk 1				Wk 2			
	A/A	F/F	SEM	<i>P</i> <	A/A	F/F	SEM	<i>P</i> <
Yield, kg/d								
Milk	3.06	2.68	0.19	NS ²	3.50	3.17	0.14	NS
FCM	4.78	4.20	0.36	NS	4.84	4.13	0.22	NS
Fat	0.20	0.18	0.02	NS	0.19	0.17	0.02	NS
Protein	0.15	0.13	0.02	NS	0.15	0.11	0.01	**
Composition, g/kg milk								
Fat	63.1	69.9	2.7	NS	53.5	52.3	1.5	NS
Protein	47.7	48.8	2.4	NS	42.2	35.9	0.8	***
BW, kg	62.3	70.9	2.9	*	58.5	63.5	1.7	*

¹Values are least squares means.²NS = non significant.**P* < 0.05.***P* < 0.01.****P* < 0.001.

yields of protein and fat, or percentages of protein and fat in milk (Table 2). During wk 2, the percentage and yield of protein were higher for the α_{S1} -CN A/A goats than for the α_{S1} -CN F/F goats. During these 2 wk, BW was lower for the α_{S1} -CN A/A goats than for the α_{S1} -CN F/F goats. Fatty acid composition of milk fat was not affected by the genotype for α_{S1} -CN (data not shown).

From wk 3 to 16, the FCM, the concentrations and yields of fat and protein were higher, and BW was lower for the α_{S1} -CN A/A goats than for the α_{S1} -CN F/F goats (Table 3). The DMI expressed on a metabolic weight basis ($BW^{0.75}$) was significantly higher throughout the trial for the α_{S1} -CN A/A goats than for the α_{S1} -CN F/F goats: 136 versus 122 (SEM = 8.2 g DM/(d * kg $BW^{0.75}$)). The NEL balance was similar between the two genotypes throughout the trial. Milk Ca and P concentrations were not affected by the genotype. The percentages of odd-numbered linear fatty acids in milk fat were higher and the percentage of myristic acid was lower for the α_{S1} -CN A/A goats than for the α_{S1} -CN F/F goats (Table 4).

From wk 3 to 16, there was no difference between diets for DMI, NE_L balance or the percentages of fat and protein in milk (Table 3). The RMY, FCM, and protein and fat yields were lower for the goats fed the LPD diet than for those fed the other diets. The goats fed the HPD diet had the highest concentrations of P and Ca in milk. In milk fat, the concentrations of butyric acid and caprylic acid were lowest for the goats fed the LPD diet; the goats fed the MPD diets had the lowest concentrations of palmitic acid in milk fat (Table 4).

From wk 3 to 16, the FCM, percentage of fat in milk, protein and fat yields, and concentrations of Ca and P decreased, whereas NE_L balance increased until it

stabilized in period 3. In milk fat, the concentrations of capric acid, lauric acid, and myristic acid were highest in period 2. Throughout the trial, the concentration of palmitic acid in milk fat increased and that of stearic acid, oleic acid, and linoleic acid decreased.

Total Tract Digestibilities and Balances

Nitrogen. Intake of N (*P* < 0.12) and fecal N (*P* < 0.13) were numerically higher for the α_{S1} -CN A/A goats than for the α_{S1} -CN F/F goats (Table 5). The amount of nitrogen excreted in urine was similar between the two genotypes. However, when expressed as a percentage of digested N, urinary N was lower for the α_{S1} -CN A/A goats than for the α_{S1} -CN F/F goats. Milk N and the efficiency of digested N in milk were higher for the α_{S1} -CN A/A goats than for the α_{S1} -CN F/F goats. Total N excretion expressed relative to milk N was lower for the α_{S1} -CN A/A goats than for the α_{S1} -CN F/F goats.

Digestibility of N, urinary N (g/d or expressed as a percentage of digested N) increased as dietary CP increased. Milk N was lower in the LPD diet than in the other diets; when expressed as a percentage of digested N, milk N decreased as the concentration of dietary CP increased. Total N excretion increased linearly relative to milk N as dietary CP concentration increased.

Digestibility of N decreased throughout the trial. Milk N (both total output and as a percentage of digested N) decreased, and total N excretion increased relative to milk N throughout the trial.

Ca and P. No difference in Ca and P inputs or outputs was observed between the genetic variants for the α_{S1} -CN. Increasing the dietary CP concentration in-

Table 3. Milk yield and composition, DMI and NE_L balance in lactating dairy goats affected by the stage of lactation, the genotype for α S1-CN in milk, and the CP concentration in the diet.¹

Measurement	Treatments									<i>P</i> <		
	Genotype for αS1-CN in milk		Diet ²			Stage of lactation ³						
	A/A	F/F	LPD	MPD	HPD	P1	P2	P3	SEM	Variant	Diet	Period
Yield, kg/d												
Milk	4.56	4.61	4.19 ^a	4.67 ^b	4.73 ^b	4.76 ^a	4.54 ^{ab}	4.30 ^b	0.08	NS	**	*
FCM	5.00 ^a	4.50 ^b	4.35 ^a	4.87 ^b	5.03 ^b	5.22 ^a	4.69 ^b	4.33 ^c	0.10	*	***	***
Fat	0.18 ^a	0.15 ^b	0.15 ^a	0.17 ^b	0.18 ^b	0.19 ^a	0.16 ^b	0.14 ^c	0.05	**	**	***
Protein	0.15 ^a	0.13 ^b	0.13 ^a	0.14 ^b	0.15 ^b	0.15 ^a	0.14 ^{ab}	0.13 ^b	0.03	*	**	*
Composition, g/kg milk												
Fat	38.8 ^a	33.5 ^b	36.0	35.6	36.9	39.7 ^a	35.5 ^b	33.3 ^c	0.7	**	NS	***
Protein	32.6 ^a	28.6 ^b	30.3	30.5	31.0	31.2	30.6	30.5	0.4	***	NS	NS
Calcium	1.32	1.29	1.26 ^a	1.24 ^a	1.37 ^b	1.40 ^a	1.28 ^{ab}	1.18 ^b	0.02	NS	*	***
Phosphorus	0.99	0.98	0.96 ^a	0.92 ^{ab}	1.06 ^b	1.06 ^a	.96 ^b	.92 ^{bc}	0.03	NS	*	***
BW, kg	58.6 ^a	67.0 ^b	61.6	63.4	63.2	61.9	62.2	64.0	1.0	*	NS	NS
DMI, kg/d	2.90	2.89	2.80	2.96	2.92	2.77	3.02	2.89	0.06	NS	NS	NS
NE _L balance, Kcal/d	-126	47	37	-22	-132	-538 ^a	202 ^b	218 ^b	92	NS	NS	***

¹Values are least squares means.²LPD = Low-protein diet (132 g CP/kg of DM), MPD = medium-protein diet (168 g CP/kg of DM), HPD = High-protein diet (198 g CP/kg of DM).³P1, P2, and P3 = wk 6, wk 11, and wk 16 postpartum, respectively.⁴NS = non significant.**P* < 0.05.***P* < 0.01.****P* < 0.001.**Table 4.** Fatty acid composition of milk fat from lactating dairy goats affected by the stage of lactation, the genotype for α S1-CN in milk, and the CP concentration in the diet.¹

Measurement	Treatments									<i>P</i> <		
	Genotype for α _{S1} -CN in milk		Diet ²			Stage of lactation ³						
	A/A	F/F	LPD	MPD	HPD	P1	P2	P3	SEM	Variant	Diet	Period
Fatty acid composition of milk fat (g/100g fat)												
C _{4:0}	1.6	1.6	1.5 ^a	1.7 ^b	1.6 ^{ab}	1.6	1.5	1.6	0.03	NS	*	NS
C _{6:0}	2.6	2.2	2.3	2.5	2.5	2.5	2.3	2.3	0.08	NS	NS	NS
C _{8:0}	3.1	3.0	2.9 ^a	3.1 ^{ab}	3.2 ^b	3.1	3.2	3.0	0.05	NS	*	NS
C _{10:0}	12.6	12.1	12.1	12.5	12.5	12.0 ^a	13.0 ^b	12.1 ^a	0.18	NS	NS	*
C _{12:0}	6.3	6.6	6.4	6.4	6.5	6.3 ^a	6.9 ^b	6.2 ^a	0.14	NS	NS	**
C _{14:0}	12.2 ^a	13.0 ^b	12.5	12.7	12.5	12.1 ^a	13.0 ^b	12.5 ^{ab}	0.13	*	NS	**
C _{15:0}	1.3 ^a	1.1 ^b	1.2	1.2	1.2	1.1 ^a	1.3 ^b	1.3 ^b	0.03	*	NS	**
C _{16:0}	31.2	31.9	32.5 ^a	30.0 ^b	32.1 ^a	27.9 ^a	32.0 ^b	34.6 ^c	0.51	NS	**	***
C _{16:1}	1.2	1.2	1.2	1.2	1.1	1.2	1.1	1.2	0.02	NS	NS	NS
C _{17:0}	0.8 ^a	0.6 ^b	0.8	0.7	0.7	0.8	0.7	0.7	0.02	*	NS	NS
C _{18:0}	5.0	4.3	4.8	4.4	4.9	5.7 ^a	4.2 ^b	4.2 ^b	0.18	NS	NS	**
C _{18:1}	13.0	13.9	12.9	12.8	14.6	16.6 ^a	12.1 ^b	11.7 ^b	0.48	NS	NS	***
C _{18:2}	2.7	2.7	2.8	2.7	2.7	2.9 ^a	2.7 ^{ab}	2.5 ^b	0.07	NS	NS	*

¹Values are least squares means.²LPD = Low-protein diet (132 g CP/kg of DM), MPD = medium-protein diet (168 g CP/kg of DM), HPD = high-protein diet (198 g CP/kg of DM).³P1, P2, and P3 = wk 6, 11, and 16 postpartum, respectively.**P* < 0.05.***P* < 0.01.****P* < 0.001.

Table 5. Nitrogen intake and utilization in lactating dairy goats affected by the stage of lactation, the genotype for α_{S1} -CN in milk, and the CP concentration in the diet.¹

Measurement	Treatments									<i>P</i> <		
	Genotype for α_{S1} -CN in milk		Diet ²			Stage of lactation ³						
	A/A	F/F	LPD	MPD	HPD	P1	P2	P3	SEM	Variant	Diet	Period
N inputs and outputs, g/d												
Intake N	76.6	71.4	57.1 ^a	76.0 ^b	88.9 ^c	72.5	73.6	75.9	2.3	NS	***	NS
Fecal N	24.1	20.7	21.1	22.5	23.7	20.0 ^a	23.0 ^{ab}	24.2 ^b	0.9	NS	NS	*
Digested N	52.4	50.8	36.0 ^a	53.5 ^b	65.3 ^c	52.5	50.6	51.7	1.9	NS	***	NS
Urinary N	20.5	21.9	10.3 ^a	21.1 ^b	32.3 ^c	20.7	20.4	22.6	1.4	NS	***	NS
Milk N	25.0 ^a	21.0 ^b	20.6 ^a	23.5 ^b	24.9 ^b	24.4 ^a	23.2 ^{ab}	21.3 ^b	0.6	**	***	**
Retained N	6.9	7.9	5.1 ^a	8.9 ^b	8.1 ^b	7.4	7.0	7.7	0.7	NS	*	NS
N partition												
Digested N / intake N	0.68	0.71	0.64 ^a	0.71 ^b	0.74 ^c	0.72 ^a	0.69 ^b	0.67 ^b	0.01	NS	***	**
Urinary N / digested N	0.37 ^a	0.42 ^b	0.29 ^a	0.40 ^b	0.50 ^c	0.37	0.39	0.42	0.01	*	***	NS
Milk N / digested N	0.50 ^a	0.44 ^b	0.58 ^a	0.44 ^b	0.38 ^c	0.49 ^a	0.48 ^{ab}	0.44 ^b	0.02	*	***	*
(Urinary N+ Fecal N)/Milk N	1.81 ^a	2.06 ^b	1.57 ^a	1.94 ^b	2.29 ^c	1.65 ^a	1.90 ^b	2.25 ^c	0.08	*	***	***

¹Values are least squares means.²LPD = Low-protein diet (132 g CP/kg of DM), MPD = medium-protein diet (168 g CP/kg of DM), HPD = high-protein diet (198 g CP/kg of DM).³P1, P2, and P3 = wk 6, 11, and 16 postpartum, respectively.**P* < 0.05.***P* < 0.01.****P* < 0.001.

creased Ca and P output in milk and apparent absorption of P (Table 6).

DISCUSSION

Regardless of the genetic variant for α_{S1} -CN, goats showed a similar pattern of increase in DMI. As previously described, DMI reached its maximal value when the RMY was at peak (Sauvant et al., 1991). Based on metabolic weight, the α_{S1} -CN A/A goats had 11% higher DMI than the α_{S1} -CN F/F: this was probably a response to the 12% increase in the energetic needs due to higher FCM. Similar NE_L balances were then calculated between the two genotypes, which indicated a similar mobilization of energy stores. This was reflected by the lack of differences in concentrations of long-chain fatty acids in milk fat. This agrees with Sauvant et al. (1991).

When feeding practice was monitored, the α_{S1} -CN A/A goats had similar milk production to the α_{S1} -CN F/F goats. This agrees with Mahé et al. (1993), but it contrasts with studies where goats were group-fed (Barbieri et al., 1995). It indicates that a direct effect of the genotype for α_{S1} -CN on milk production is unlikely. The lack of relationship between the RMY and the concentration of protein in milk (see below) is rather surprising because of the well-demonstrated negative relationship between these two variables. In fact, this negative correlation reflects the relationships between the polygenes that regulate the synthesis of the different constituents of milk. In our case, the different genotypes

are supposed to differ only by the gene of structure of the α_{S1} -CN, the other genes being statistically the same (Martin and Grosclaude, 1993).

The overall mean for the concentration of protein in milk was 4.0 g/kg of milk higher for the α_{S1} -CN A/A goats than for the α_{S1} -CN F/F goats. This value is slightly lower than those previously recorded during the entire lactation (Barbieri et al., 1995) or in mid-late lactation (Grosclaude et al., 1987; Mahé et al., 1993). Assuming that caseins represent 80% of the milk proteins, the substitution of an allele with a low synthesis rate (F) by an allele with a high synthesis rate (A) would induce an increase of 2 g CN/kg of milk, i.e., 2.5 g protein/kg of milk. Consequently, the difference in milk protein content between the α_{S1} -CN A/A goats and the α_{S1} -CN F/F goats was found to be 5 g/kg of milk (Barbieri et al., 1995), a value that was only determined after the peak of milk production in our trial, when NE_L balance was positive. This could indicate that the maximal difference between the two genetic variants of the concentration of protein in milk is dependent upon the energy status of the goat. Indeed, milk protein content is altered by the supply of dietary energy (de Peters and Cant, 1992).

Another possibility is that some of the mechanisms through which the concentration of protein in milk content is decreased in the α_{S1} -CN F/F goats are progressively expressed during the early lactation. It has been shown that compared with the α_{S1} -CN A/A goats, the decrease in the α_{S1} -CN content for the α_{S1} -CN F/F goats

Table 6. Calcium and phosphorus balances in lactating dairy goats affected by the stage of lactation, the genotype for α S1-CN in milk, and the CP concentration in the diet.¹

Measurement	Treatments									<i>P</i> <		
	Genotype for ql α _{S1} -CN in milk		Diet ²			Stage of lactation ³						
	A/A	F/F	LPD	MPD	HPD	P1	P2	P3	SEM	Variant	Diet	Period
Calcium inputs and outputs, g/d												
Intake	38.31	35.60	36.29	39.39	35.19	34.64	38.00	38.22	0.95	NS	NS	NS
Fecal	32.79	30.43	31.67	32.43	30.72	29.77	31.76	33.29	1.06	NS	NS	NS
Urinary	0.78	0.73	0.79	0.75	0.73	0.76	0.72	0.78	0.15	NS	NS	NS
Milk	5.84	5.53	5.17 ^a	5.78 ^{ab}	6.11 ^b	6.50 ^a	5.67 ^{ab}	4.88 ^b	0.19	NS	*	***
Retained	-1.10	-1.08	-1.34	0.43	-2.36	-2.39	-0.15	-0.73	0.58	NS	NS	NS
Apparent absorption %	14.74	14.15	12.77	17.83	12.72	13.97	16.12	13.23	1.33	NS	NS	NS
Phosphorus inputs and outputs, g/d												
Intake	12.74	12.30	11.69	13.08	12.78	12.46	12.36	12.73	0.32	NS	NS	NS
Fecal	7.37	6.76	7.05	7.35	6.79	6.62	6.76	7.82	0.29	NS	NS	NS
Urinary	0.56	0.97	0.70	0.65	0.95	0.85	0.69	0.76	0.12	NS	NS	NS
Milk	4.33	4.31	3.95 ^a	4.24 ^{ab}	4.76 ^b	4.86 ^a	4.24 ^{ab}	3.86 ^b	0.12	NS	**	***
Retained	0.47	0.26	0.00	0.83	0.28	0.13	0.68	0.29	0.14	NS	NS	NS
Apparent absorption %	42.52	45.99	41.36 ^a	43.77 ^{ab}	47.64 ^b	47.65 ^a	45.96 ^{ab}	39.15 ^b	1.47	NS	**	**

¹Values are least squares means.²LPD = Low-protein diet (132 g CP/kg of DM), MPD = medium-protein diet (168 g CP/kg of DM), HPD = high-protein diet (198 g CP/kg of DM).³P1, P2, and P3 = wk 6, 11, and 16 postpartum, respectively.**P* < 0.05.***P* < 0.01.****P* < 0.001.

was associated with a lower amount of mammary mRNA for CN (Martin and Grosclaude, 1993). More recently, the maturation of newly synthesized caseins and their transport for secretion by the mammary epithelial cell was shown to be delayed in the α S1-CN F/F goats compared with the α S1-CN A/A goats, thus inducing their accumulation in the acini (Chanat et al., 1999). It is not known if these mechanisms are affected by the stage of lactation.

To our knowledge, there has been no study reporting N utilization and partition in goats differing by the genetic variant for α S1-CN. Compared to the α S1-CN F/F goats, the α S1-CN A/A goats digested N was converted to milk N more efficiently at the expense of urinary waste; this was obtained independently of the dietary CP concentration, which indicates that the recommendation for dietary N (INRA, 1989) can be used for the two genotypes.

Our results confirm the relationship between polymorphism in the goat and concentrations and yield of fat in milk (Grosclaude et al., 1987; Mahé et al., 1993). This was not due to differences in adipose tissue mobilization, as NE_L balance and long-chain fatty acid in milk were not affected by the genotype for α S1-CN. These differences in milk fat content could indicate a higher synthesis of fat in the mammary gland of the α S1-CN A/A goats than in the α S1-CN F/F goats. No association between the α S1-CN genotype and the concentration of

fat in milk has been reported in cows (Ng-Kway-Hang, 1998) or in ewes (Pirisi et al., 1999), but other results (Bolla et al., 1989; Ng-Kway-Hang, 1998) have shown that the polymorphism for the α S1-CN is associated with low levels of fat in milk. The allele for α S1-CN probably does not play a direct role in fat synthesis in the mammary gland. We can easily hypothesize that a more important secretion of the CN could induce a mechanical disturbance of the secretion of fat by a mechanism that remains to be found.

The concentrations of Ca and P in milk were within the range of published data (Kessler, 1991; Guéguen, 1997). In contrast with the results of Grosclaude et al. (1994), we did not observe a higher amount of Ca in milk for the α S1-CN A/A goats than for the α S1-CN F/F goats (Table 6). Higher protein content should logically increase the concentration of Ca in milk, as 60 to 70% of milk Ca is represented by Ca phospho-caseinate.

The decrease in Ca and P content of milk in the advanced stage of lactation is well established (Guéguen, 1997). A close relationship between Ca, P and, fat content of milk has been observed in cows (NRC, 1989) and in goats (AFRC, 1997) in the various stages of lactation.

This trial also attempted to determine the dietary CP concentration needed to optimize N partition toward milk protein at the expense of N excretion in goats no matter what genotype for α S1-CN is present. In our trial, increasing CP concentration from 13 to 20% led

to a linear increase in the protein yield, which resulted from a significant increase in RMY (from 13 to 17% CP) and a nonsignificant increase in milk protein content (from 13 to 20% CP). Increasing the dietary CP concentration had a positive effect on the yield of protein (Kung and Huber, 1983; Leonard and Block, 1988), but not in every case (Ha and Kennely, 1984). These differences could reflect differences in NE_L density between diets, as the increase in milk protein content when dietary CP increased is higher with a low- than with a high-energy diet (McLeod et al., 1984). Another possibility relies on the availability of absorbed AA for milk protein synthesis, particularly lysine and (or) methionine (Becquette et al., 1998). In our trial, methionine probably limited the three diets, because its concentration was considerably below recommendations (INRA, 1989).

The N balance clearly illustrated the fluctuation in N and the division of digested N for the three diets. Excess dietary N is excreted at a faster rate in urine than in feces; when digested N increased by a factor 1.8 (LPD vs. HPD), urinary N excretion increased by a factor 3.1. With the LPD, urinary N was lower than fecal N, and it represented only 30% of total N excreted; with the HPD, urinary N excretion represented 50% of digested N, and it was the main route of N excretion. Numerous studies in early lactation have shown that when dietary CP is above 14 to 16%, urinary N becomes the main route of excretion of excess dietary N (Brun-Bellut et al., 1990; Leonard and Block, 1988). The effect of the high dietary CP concentration on urinary excretion may have been confused with the effect of dietary starch concentration in our trial, however. Indeed, barley was substituted with soybean meal to increase dietary CP, with a high starch, low CP concentration in the LPD and a low starch, high CP concentration in the HPD. In these conditions, energy availability may have been insufficient for protein synthesis in the rumen with the HPD. The difference in daily starch intake between LPD and HPD was approximately 300 g, which represented 270 g of OM fermented in the rumen with a ruminal starch degradation of barley of 0.89 (Offner et al., 2001). This represented between 5 and 10 g less in N uptake by rumen microorganisms, assuming that the efficiency of microbial synthesis ranges between 20 and 40 g of N/kg of OM digested in the rumen (Stern et al., 1994). In these conditions, the lower starch intake for goats fed the HPD than for goats fed the LPD may have accounted for 25 to 50% of the difference in urinary N excretion.

Digested N was used efficiently for milk N output even in the highest dietary CP concentration, probably because sufficient energy was available for milk synthesis. As previously observed, however, (Weigel et al., 1997), the efficiency of digested N for N utilization in

milk increased as the dietary CP concentration decreased. This improvement in N efficiency has important implications for dairy producers and the environment (Tamminga, 1992). Feeding goats the LPD rather than the HPD reduced total N waste (fecal plus urinary) more than 75% (56.0 vs 31.4 g N/d for the HPD and LPD, respectively), and there was also an improvement in the percentage of digested N that was secreted in milk. Compared to the HPD, the slightly lower milk N output on the LPD (−4.3 g N/d) was associated with a decrease in total N wastes (−24.6 g N/d), equivalent to 5.3 g N wasted/g of milk N. This shows the low biological and environmental efficiency of feeding goats additional protein, although the higher price of milk with higher protein content may make this choice financially attractive.

Milk fat percentage was not affected by the dietary CP concentration as previously reported by Kalscheur et al. (1999) and Weigel et al. (1997) but in contrast to Leonard and Block (1988). These differences could reflect differences in the fiber content of diets, as increasing dietary CP concentration increased milk fat content on low-fiber diets but not on high-fiber diets (Jaquette et al., 1986). Goats fed the higher dietary CP concentration had higher yield of fat, more negative NE_L balance, and higher concentrations of the sum of long-chain fatty acids as previously reported (Kalscheur et al., 1999; Leonard and Block, 1988).

Increasing dietary CP concentration increased Ca and P content of milk, but there is no obvious reason to explain these observations.

The low values observed for apparent absorption of Ca could be due to the level of Ca intake (160 % of the requirements) and/or to the diet ingredients; almost all Ca was supplied by alfalfa pellets and sugar beet pulp silage, which have a low Ca availability. A calculation of true absorption, based on theoretical endogenous fecal loss (Kessler, 1991), leads to a mean value (all observations pooled) of 20%, which agrees with data obtained in cattle for alfalfa (30%; Ward et al., 1979) and in sheep for sugar beet pulp (20%; Meschy and Guéguen, 1992).

The apparent absorption of P was within the ranges published and decreased as is typical during the lactation (Meschy, 2000). The higher apparent absorption of P with HPD than with LPD was probably related more to the diet composition (substitution of barley with soybean meal) than to the CP level of diets.

CONCLUSIONS

By a careful genetic selection of variants with a high synthesis rate of CN, it is possible to increase protein and fat in milk to improve the cheese-making properties of goat milk without a decrease in milk production.

Feeding these goats a diet formulated to reduce N wastes could minimize the impact on the environment, result in a more sustainable dairy industry.

REFERENCES

- AFRC, 1997. Technical Committee on Responses to Nutrients. Report 10. The nutrition of goats. *Nutr. Abstr. Rev. (Series B)* 67:765–830.
- Barbiéri, M. E., E. Manfrédi, J. M. Elsen, G. Ricordeau, J. Bouillon, F. Grosclaude, M. F. Mahé, and B. Bibé. 1995. Effect of the α S1-casein locus on dairy performances and genetic parameters of alpine goats. *Genet. Sel. Evol.* 27:437–450.
- Bas, P. 1985. Extraction rapide de la matière grasse pour la détermination de sa composition en acide gras. *Cah. Techn.* 9:21–24.
- Becquette, B. J., F. R. C. Backwell, and L. A. Crompton. 1998. Current concepts of amino acid and protein metabolism in the mammary gland of the lactating ruminant. *J. Dairy Sci.* 81:2540–2559.
- Bolla, P., A. Carolli, A. Mezzelani, R. Rizzi, G. Pagnacco, A. Fraghy, and S. Casu. 1989. Milk protein markers and production in sheep. *Anim. Genet.* 1:78–79.
- Brown, J. R., A. J. R. Law, and C. H. Knight. 1995. Changes in composition of goat's milk during the course of lactation: physiological inferences and technological implications. *J. Dairy Res.* 62:431–439.
- Brun-Bellut, J., G. Blanchart, and B. Vignon. 1990. Effect of rumen-degradable protein concentration in diet on digestion, nitrogen utilization and milk yield by dairy goats. *Small Ruminant Res.* 3:575–581.
- Chanat, E., P. Martin, and M. Ollivier-Bousquet. 1999. α S1-casein is required for the efficient transport of β - and κ -casein from the endoplasmic reticulum to the Golgi apparatus of mammary epithelial cells. *J. Cell Sci.* 112:3399–3412.
- DePeters, E. J., and J. P. Cant. 1992. Nutritional factors influencing the nitrogen composition of bovine milk: a review. *J. Dairy Sci.* 75:2043–2070.
- Grosclaude, F., M. F. Mahé, G. Brignon, L. Di Stasio, and R. Jeunet. 1987. A mendelian polymorphism underlying quantitative variations of goat α S1-casein. *Genet. Sel. Evol.* 19:399–412.
- Grosclaude, F., G. Ricordeau, P. Martin, L. Vassal, and J. Bouillon. 1994. From gene to cheese: the caprine α S1-casein polymorphism, its effects and its evolution. *INRA Prod. Anim.* 7:3–19.
- Guéguen, L. 1997. The nutritional value of minerals in goat milk. Pages 67–80 in *Intérêts Nutritionnel et Diététique du Lait de Chèvre*. G. Freund, ed. INRA, Paris, France.
- Ha, J. K., and J. J. Kennely. 1984. Effect of protein on nutrient digestion and milk production by Holstein cows. *J. Dairy Sci.* 67:2302–2307.
- INRA, 1989. Ruminant Nutrition. Recommended Allowance and Feed Table. R. Jarrige, ed. *Inst. Natl. Rec. Agron.*, Paris, France.
- Jaquette, R. D., A. H. Rakes, and W. J. Croom. 1986. Effect of dietary protein on milk, rumen, and blood parameters, in cattle fed low fiber diets. *J. Dairy Sci.* 69:1026–1034.
- Kalscheur, K. F., J. H. Vandersall, R. A. Erdman, R. A. Kohn, and E. Russek-Cohen. 1999. Effects of dietary crude protein concentration and degradability on milk production responses of early, mid, and late lactation dairy cows. *J. Dairy Sci.* 82:545–554.
- Kessler, J. 1991. Mineral nutrition of goats. Pages 104–119 in *Goat Nutrition*. P. Morand-Fehr, ed. Pudoc, Wageningen, The Netherlands.
- Kung, L., and J. T. Huber. 1983. Performance of high producing cows in early lactation fed protein of varying amount, sources, and degradability. *J. Dairy Sci.* 66:227–234.
- Leonard, M., and E. Block. 1988. Effect of ration protein content and solubility on milk production of primiparous Holstein heifers. *J. Dairy Sci.* 71:2709–2722.
- Mahé, J. F., and F. Grosclaude. 1989. α S1-Cn^D, another allele associated with a decreased synthesis rate at the α S1-casein locus. *Genet. Sel. Evol.* 21:127–129.
- Mahé, M. F., E. Manfredi, G. Ricordeau, A. Piacère, and F. Grosclaude. 1993. Effects of the α S1-casein polymorphism on goat dairy performance: a within-sire analysis of alpine bucks. *Genet. Sel. Evol.* 26:151–157.
- Martin, P. and F. Grosclaude. 1993. Improvement of milk protein quality by gene technology. *Livestock Prod. Sci.* 35:95–115.
- McLeod, G. K., D. G. Grieve, I. McMillan, and G. C. Smith. 1984. Effect of varying protein percent and energy densities in complete rations fed to cows in first lactation. *J. Dairy Sci.* 67:421–429.
- Meschy, F. 2000. Recent progress in the assessment of mineral requirements of goats. *Livest. Prod. Sci.* 64:9–14.
- Meschy, F. and L. Guéguen. 1992. Calcium availability from sugar beet pulps. Pages 520–521. in 43rd Eur. Ass. Anim. Prod. Meeting, Madrid.
- National Research Council. 1981. Nutrient Requirements of Goats: Angora, Dairy, and Meat goats in Temperate and Tropical Countries. *Natl. Acad. Sci.*, Washington, DC.
- National Research Council. 1989. Nutrient Requirements of Dairy Cattle. 6th rev. ed. *Natl. Acad. Sci.*, Washington, DC.
- Ng-Kway-Hang, K. F. 1998. Genetic polymorphism of milk proteins: relationships with production traits, milk composition and technological properties. *Can. J. Anim. Sci.* 78(suppl):132–147.
- Offner, A., D. Sauvant, P. Chapoutot, J. van Eys, and A. Bach. 2001. Quantitative analysis of in situ starch degradation in the rumen. *J. Dairy Sci.* 84(suppl. 1):80.(Abstr.).
- Pirisi, A., G. Pirreda, C. M. Pappof, R. di Salvo, S. Pintus, G. Garro, P. Ferranti, and L. Chianese. 1999. Effect of sheep α S1-casein CC, CD and DD genotypes on milk composition and cheese making properties. *J. Dairy Res.* 66:409–419.
- Sauvant, D., P. Morand-Fehr, and S. Giger-Reverdin. 1991. Dry matter intake of adult goats. Pages 25–36 in *Goat Nutrition*. P. Morand-Fehr, ed. Pudoc, The Netherlands.
- SAS/STAT User's Guide, Version 8 Edition. 2000. SAS Inst., Inc., Cary, NC.
- Schmidely, Ph., M. Lloret-Pujol, P. Bas, A. Rouzeau, and D. Sauvant. 1999. Influence of feed intake and source of dietary carbohydrate on milk yield and composition, nitrogen balance, and plasma constituents of lactating goats. *J. Dairy Sci.* 82:747–755.
- Stern, M. D., G. A. Varga, J. H. Clark, J. L. Firkins, J. T. Huber, and D. L. Palmquist. 1994. Evaluation of chemical and physical properties of feeds that affect protein metabolism in the rumen. *J. Dairy Sci.* 77:2762–2786.
- Tamminga, S. 1992. Nutrition management of dairy cows as a contribution to pollution control. *J. Dairy Sci.* 75:345–347.
- Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and non starch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74:3583–3597.
- Ward, G., L. H. Harbers, and J. J. Blaha. 1979. Calcium containing crystals in alfalfa: their fate in cattle. *J. Dairy Sci.* 62:715–722.
- Weigel, D. J., J. P. Elliot, and J. H. Clark. 1997. Effect of amount and ruminal degradability of protein and nutrient digestibility of protein on nutrient digestibility and production by cows fed tallow. *J. Dairy Sci.* 80:1150–1159.