Effects of the percentage of concentrate on rumen fermentation, nutrient digestibility, plasma metabolites, and milk composition in mid-lactation goats

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ABSTRACT

The aim of this work was to study the effects of the dietary percentage of concentrate on patterns of intake, the evolution of rumen fermentation characteristics and plasma metabolites after a meal, nutrient digestibility, and milk production and composition in a medium-term trial in dairy goats. These effects have been well studied in dairy cattle but seldom in goats. Thirteen ruminally and duodenally cannulated dairy goats (95 ± 4 d in milk) fed ad libitum were used in this study. Goats were assigned to 1 of 2 dietary treatments: high-concentrate (70% concentrate on dry matter basis) or a low-concentrate (35%) total mixed rations. The experiment was conducted over a period of 10 wk, including 3 wk of adaption to the diets. Patterns of intake, rumen fermentation characteristics, and plasma metabolites after a meal and fatty acids profile of milk fat were compared at the onset and at the end of the experiment. The increase in dietary percentage of concentrate decreased rumen pH, acetate to propionate ratio, ammonia-N concentration, and plasma urea concentration. The percentage of concentrate did not affect total volatile fatty acid concentrations. The high-concentrate diet increased the rate of intake during the morning meal at the onset of the experiment, whereas it decreased total dry matter intake and the rate of intake during the morning meal at the end of the experiment. The high-concentrate diet resulted in greater organic matter digestibility. Raw milk yield and protein yield were greater in goats fed the high-concentrate diet, whereas fat yield was not affected by dietary treatments. The milk fat content was lower in goats fed the high-concentrate diet. Proportions of the *trans*-C18:1 isomer relative to total fatty acids in milk were higher with the high-concentrate diet, but no modification of the proportion of total *trans*-C18:1 was detected, in particular no shift from *trans*-11 C18:1 to *trans*-10 C18:1 was observed. Further, the isomer

trans-10, *cis*-12 C18:2 was not detected. Data from this study could be used for a new modeling approach or to improve existing models.

Key words: dairy goat, percentage of concentrate, rumen, milk composition

INTRODUCTION

European consumption of goat milk products has increased for more than 20 yr, and farmers have responded by increasing goat milk production (FAO, 2010). An increase in milk production is generally achieved by the use of high-concentrate diets (Morand-Fehr et al., 2007) at the expense of milk fat content (MFC) and sometimes with higher milk protein content (MPC; Schmidely and Sauvant, 2001; Chilliard and Ferlay, 2004). With high-concentrate diets, the proportions of fatty acids (FA) in MFC are generally altered toward a decrease in short- and medium-chain FA (C12 to C16) and an increase in proportions of total *trans* C18:1 isomers (Calderon et al., 1984; Ledoux et al., 2002; Andrade and Schmidely, 2006).

Feeding behavior can be modified by feeding high-concentrate diets (Abijaoudé et al., 2000b; Desnoyers et al., 2008a). Goats fed a diet with 60 compared 30% concentrates spent less time eating and ruminating and more time resting during the hours following the meal distribution (Desnoyers et al., 2008a). Moreover, goats fed high-concentrate diets had lower digestibility of dietary fiber (Kawas et al., 1991), as was also observed in bovine species (see reviews of Huhtanen et al., 2009; Nousiainen et al., 2009). This is associated with changes in the ruminal microbial ecosystem because of a decrease in rumen pH when the percentage of concentrate increases (Archimède et al., 1996).

Unlike the situation in dairy cows (Khorasani and Kennelly, 2001; Lechartier and Peyraud, 2010), few studies have been conducted in which the effects of a high-concentrate diet on intake behavior, fermentation characteristics in the rumen, and milk yield and composition were measured simultaneously, at different time scales (either after feeding or over several weeks; Kawas et al., 1991; Santini et al., 1992). The objectives

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of this study were to determine the effects of the dietary percentage of concentrate on (1) intake behavior, ruminal measurements, and plasma metabolites after feeding; (2) in sacco and in vivo digestibility of the dietary constituents; and (3) milk production and milk composition during a 10-wk trial.

MATERIALS AND METHODS

Animals, Design, Diets, and Feeding

Goats were cared for and handled in accordance with the French legislation on animal experimentation in line with the *European Convention for the Protection of Vertebrates used for Experimental and other Scientific Purposes* (European Directive 86/609). Thirteen ruminally and duodenally cannulated Saanen or Alpine goats (BW = 62 ± 4 kg; parity = 3 ± 1 lactation) were used in a 10-wk trial, starting 10 wk after surgical cannulation. At the onset of the trial, goats were 95 ± 4 DIM, with 3.3 ± 0.38 kg/d of raw milk yield (RMY), an MFC of 38.0 ± 5.11 g/kg, and an MPC of 32.7 ± 2.46 g/kg. Goats were housed in individual pens throughout the trial, except for 3 wk when they were housed in individual metabolism crates for determination of diet digestibility.

At the onset of the trial (wk 1), goats were fed a basal TMR containing 52.5% concentrate for 1 wk. At the end of this first week, goats were randomly assigned to 1 of 2 experimental groups, according to their parity, their RMY during this week, and their MFC and MPC. Goats were then progressively switched from the basal TMR to their experimental TMR over wk 2 by increasing or decreasing by 5% the proportion of the concentrate in the TMR every 2 d until the concentrate proportions of the experimental diets were achieved. The experimental TMR (Table 1) contained either a high percentage of concentrate (**H**, 70% concentrate/DM, 6 goats) or a low percentage of concentrate (**L**, 35% concentrate/DM, 7 goats). Goats were fed ad libitum (approximately 10% of refusals) for 8 wk. Feed was offered individually twice a day at 0800 and 1600 h, after milking, with two-thirds allocated in the afternoon and one-third in the morning, according to the time interval between milkings. Energy (NE_L) and nitrogen (digestible protein in the intestine, **PDI**) values of the feed and TMR were calculated according to the additive method from INRA tables (Baumont et al., 2007). The forage was a mixture of grass hay (46% of forage DM) and dehydrated alfalfa (Rumiluz, Désialis, Paris, France; 54% of forage DM). The concentrate was composed of a commercial concentrate (Agralys Aliment, Châteaudun, France) and sugar beet pulp silage. Soybean meal and calcium palm oil salt were added to

the concentrate part of the L diet and basal diet so that the 3 TMR had similar calculated CP and total FA contents, respectively. Feed offered and refusals were individually weighed daily. Distributed feed and refusals samples were taken at wk 1 for the basal diet and at wk 4, 6, and 10 for the experimental TMR. Samples of feed were oven-dried at 87°C for 24 h and ground through a 1-mm sieve before being analyzed.

Animal Performance

Goats were weighed weekly in the middle of the day (1400 h). They were milked twice a day, at 0700 and 1530 h. Milk samples were taken weekly from 2 consecutive milkings and stored at 4°C with bronopol (Trillard, Surgères, France) until analysis of fat, protein, and lactose contents. Milk samples were also taken at wk 1, 6, and 10 and were frozen without preservative at -20°C for analysis of milk FA profile.

From the onset of the trial, blood samples were taken weekly, before the morning feeding, in heparinized tubes from the jugular vein. They were immediately centrifuged, and plasma was stored at -20°C until analysis of glucose, NEFA, urea, BHBA, insulin, L-lactate, and osmotic pressure. A supplementary blood sample was collected for immediate analysis of blood pH and blood bicarbonate concentration (SAS ABL77, Radiometer Analytical, Neuilly-Plaisance, France).

Patterns of DMI, Ruminal Fermentation, and Plasma Concentrations After Feeding

At wk 1, 4, and 10, the dynamic patterns of intake were recorded by weighing devices placed under the feed trough, which recorded the weight of feed in the trough every 2 min (Desnoyers et al., 2008a). The recordings were made for each goat during 4 successive morning meals of each week.

At wk 4 and 10, 50 mL of rumen contents was individually collected at 0, 1, 2, 4, and 6 h after the morning feeding on the fourth day of intake recording. Rumen pH and redox potential (equilibrium value after 30 min) were measured and 4 aliquots were taken at each time. Filtered rumen fluid (3 mL) was acidified with 25% H₃PO₄ (vol/vol) and stored at -20°C until analysis of VFA. A second aliquot of rumen fluid (6 mL) was mixed with 12.5% TCA (vol/vol) and kept at -20°C until analysis of ammonia-N (NH₃-N). A third aliquot of rumen fluid (3 mL) was mixed with 0.15% HCl (vol/vol) and stored at -20°C for analysis of soluble carbohydrate. The fourth aliquot was stored without preservative at -20°C for analysis of osmotic pressure.

Ten milliliters of blood was individually collected from the jugular vein in heparinized tubes on the same

Table 1. Ingredient composition, chemical composition, and nutritive values of low- (L) and high- (H) concentrate diets

Item	Diet		SEM	<i>P</i> -value
	L	H		Concentrate ¹
Ingredients (g/100 g of DM)				
Forage	65	30		
Grass hay	29.9	13.8		
Dehydrated alfalfa	35.1	16.2		
Concentrate	35	70		
Commercial concentrate ²	20	50		
Sugar beet pulp silage	7	20		
Calcium palm oil salt	1.4	—		
Soybean meal	6.6	—		
Chemical composition ³ (g/100 g of DM)				
CP	16.7	17.7	0.37	0.18
NDF	40.9	36.0	1.47	0.04
ADF	24.4	20.1	0.97	0.01
Acid detergent lignin	3.89	2.97	0.303	0.06
Starch	4.38	9.70	—	—
Ash	8.47	8.37	0.202	0.72
Fatty acid (FA)	2.33	2.81	0.750	0.04
Total FA (g/100 g of FA)				
C _{12:0} –C _{15:0}	1.89	0.78	0.078	0.01
C _{16:0}	37.3	16.41	0.070	<0.001
C _{18:0}	4.5	3.41	0.029	0.001
<i>cis</i> -9 C _{18:1}	23.5	29.2	0.17	0.002
<i>cis</i> -9,12 C _{18:2}	17.3	33.1	0.05	<0.001
<i>cis</i> -9,12,15 C _{18:3}	9.2	10.4	0.05	0.003
C _{20:0} –C _{24:0}	1.47	1.45	0.031	0.70
Nutritive value				
Electrolytic balance ⁴ (mEq/kg of DM)	500	419		
Net energy ⁴ (MJ/kg of DM)	5.88	6.75		
PDIN ^{4,5} (g/kg of DM)	113	114		
PDIE ^{4,5} (g/kg of DM)	104	114		

¹Effect of the percentage of concentrate.²18% maize, 14% sugar beet pulp, 12% sunflower meal, 10% wheat, 10% soybean, 9% rapeseed meal, 6% soybean meal, 4% wheat distiller, 3.5% linseed, 3% pea seed, 1% rapeseed oil, 3% molasses, 6.5% mineral and vitamin premix.³*n* = 7 for analysis of NDF, ADF, acid detergent lignin, ash contents; *n* = 2 for CP and FA contents; *n* = 1 for starch content.⁴Calculated according to the additive method from INRA tables (Baumont et al., 2007).⁵PDIN (or E) = protein digestible at the level of intestine when nitrogen (or energy) is limiting for microbial protein synthesis.

days as samplings of rumen contents, at 0, 0.5, 1, 1.5, 2, 3, 4, and 6 h after the morning meal. Samples were immediately centrifuged for 10 min at $3,000 \times g$ at a temperature of 5°C, and plasma was stored at –20°C until analysis of glucose, NEFA, urea, BHBA, insulin, L-lactate, and osmotic pressure.

In Situ Ruminal Degradability of Substrate

In wk 9, ruminal degradability of DM, NDF, ADF, and starch in 12 goats (6 for each group) was determined by using the nylon bag procedure derived from Vérité et al. (1987). Two ingredients were incubated: grass hay of the diets (to measure the DM, NDF, and ADF degradability) and maize grain (to measure DM

and starch degradability). Samples of ingredients were ground through a 1-mm screen. Nylon bags (44-μm pore size, 6 cm × 15 cm, SaatiTech, Appiano Gentile, Italy) containing 3 g of ingredient were incubated in triplicate (1 d for each replicate) for 4, 8, 16, 24, and 48 h for grass hay and for 2, 4, 8, 16, and 24 h for maize. When removed from the rumen, bags were rinsed in cold water and washed for 10 min in cold water to remove rumen particles and rumen microbes attached to substrates. Bags were then frozen to stop fermentation. After freezing, they were dried in an air-oven at 60°C for 48 h, and then analyzed for DM. Residues from bags were pooled within each goat for the incubation duration and then analyzed for NDF and ADF (grass hay) and starch (maize).

Whole-Tract Digestibility

To measure the apparent fecal digestibility of diets (6 goats per diet), feed offered, refusals, and total feces were weighed daily during 5 consecutive days in wk 6. Aliquots of refusals and feces were collected daily at the same time, pooled by animal at the end of the 5 d, dried in an air-oven at 87°C for 24 h, and ground through a 1-mm sieve before analyses of DM, NDF, ADF, and starch.

Analytical Procedures

The DM contents of TMR, refusals, feces, and nylon bag residues were determined by oven-drying at 103°C for 24 h. The NDF content was estimated by the method of Van Soest and Wine (1967) modified by Giger et al. (1987) with the use of a heat stable α -amylase but without sodium sulfite and decalin. The contents of ADF and acid detergent lignin were obtained using a sequential approach on the NDF residue (Giger et al., 1987). Ash and starch contents were analyzed according to ISO (1978) and AFNOR (1997) methods, respectively. Total N was determined by the Dumas technique (Sweeney and Rexroad, 1987).

Concentrations of $\text{NH}_3\text{-N}$ and soluble carbohydrate of rumen fluid were analyzed with an autoanalyzer (Technicon, Oise, France), according to the methods of Weatherburn (1967) and Brown and Boston (1961), respectively. Concentrations of VFA were determined by gas chromatography (Kristensen, 2000). Osmotic pressures of rumen fluid and plasma were determined using an osmometer (Mark3, Fiske, Radiometer Analytical). Plasma samples were analyzed using a Cobas Mira-analyzer (Roche, Mannheim, Germany) with commercial kits for glucose (Glucose-quant, Glucose/HK, Roche), NEFA [NEFA-HR(2), Wako Chemical GmbH, Neuss, Germany], urea (Urea/BUN, Roche) and L-lactate (Lactate, Roche). The BHBA concentrations were analyzed by the procedure of Barnouin et al. (1986). Insulin was analyzed using ELISA kits (Mercodia Ovine Insulin ELISA, Uppsala, Sweden).

Fat and protein contents of milk were analyzed by infrared spectrophotometry (Syndicat Interdépartemental de l'Élevage, Le Mée, France). Analysis of milk and diet FA contents and profiles was described by Andrade and Schmidely (2006).

Calculations and Statistical Analysis

The rate of feed intake and the cumulated DMI after each feeding, expressed in grams per kilogram of BW were calculated from the recordings of the weight of feed in the trough every 2 min (Desnoyers et al., 2008a).

The following nonlinear model (Baumont, 1988) was then applied to each profile (for each goat and each recording day) using the NLIN procedure of SAS (SAS Institute, 2000):

$$\text{Cumulative DMI (t)} = A(1 - e^{-Bt}),$$

where A is the asymptote, $A \times B$ the slope of the curve, and t the time after feeding.

For each period and goat, pH data were described by a third-degree polynomial model as described by Dragomir et al. (2008). The minimal pH, initial pH, the amplitude of the pH decrease (initial pH – minimal pH), and the time when the rumen pH was below 6.0 were calculated. Daily DMI and RMY were averaged by goat and by week.

The fitted parameters of the DMI patterns, the parameters on pH profiles after feeding, ruminal and plasma data, and weekly performance data were analyzed using the mixed procedure of SAS (SAS Institute, 2000) for repeated measurements. The model included fixed effects of the percentage of the concentrate, the week, the interaction between the percentage of concentrate and the week, and an appropriate covariate (value in wk 1). Animal was considered as a random effect. For ruminal and plasma data, the fixed effects of the time after feeding and its interaction with the percentage of concentrate were included in the model. The repeated measurements were applied to the time after feeding and not to the week, and no covariate was used. For the fitted parameters of the DMI patterns, we added a fixed effect of recording day. The models were tested with 4 covariance structures: compound symmetry, heterogeneous compound symmetry, first-order autoregressive, and heterogeneous autoregressive (1). The covariance structure that provided the smallest Akaike's information criteria was selected.

In sacco disappearance of DM, calculated from its proportion remaining in the bag after incubation in the rumen, was determined for each nylon bag. The DM disappearance was averaged by goat and by incubation time (triplicate). In sacco degradability of NDF and ADF (for grass hay) and starch (for maize) were then calculated. Calculated DM, NDF, ADF, and starch disappearances were described with the nonlinear model of Ørskov and McDonald (1979):

$$\text{Disappearance} = a + b(1 - e^{-ct}),$$

where a is the soluble fraction (% of total DM, NDF, ADF, or starch), b the degradable fraction (% of total DM, NDF, ADF, or starch), t the time of rumen incubation (h), and c the relative rate of degradation

of fraction b (h^{-1}). Nonlinear parameters a , b , and c were estimated using the NLIN procedure of SAS (SAS Institute, 2000). The effective degradability of DM (EDDM), NDF (EDNDF), ADF (EDADF), and starch (EDS) were calculated as:

$$\text{EDDM, EDNDF, EDADF, or EDS} = a + [(b \times c)/(c + k)],$$

where k is the estimated rate of outflow from the rumen, fixed at 0.06 h^{-1} (Vérité et al., 1987).

In sacco DM data (parameters a , b , c , and EDDM) were analyzed using the GLM procedure of SAS (SAS Institute, 2000) with a model including the percentage of concentrate, the fixed effect of the animal, and day. As residues from bags were pooled within each goat for analysis of NDF, ADF, or starch, NDF, ADF, and starch disappearance data were analyzed using the GLM procedure of SAS with only a test of the effect of the diet. The same model was applied to data of apparent fecal digestibility.

Milk FA proportions measured at wk 6 and 10 were averaged by goat, and preliminary statistical analysis indicated no significant effect of week on any FA proportions. Individual data of milk FA were analyzed using the GLM procedure of SAS (SAS Institute, 2000) with a model including the percentage of concentrate and the appropriate covariate obtained in wk 1. All data presented in this paper are least squares means $\pm$ SEM.

RESULTS

Chemical Composition and Nutritive Values of the Diets

The H diet had lower NDF and ADF contents and higher contents of starch and FA than the L diet (Table 1). The H diet had lower proportions of C16:0 and C18:0 and higher proportions of *cis*-9 C18:1, *cis*-9, *cis*-12 C18:2, and *cis*-9, *cis*-12, *cis*-15 C18:3 in dietary FA than the L diet.

DMI

The effects of recording day and percentage of concentrate on the parameters calculated to assess the DMI pattern after a meal were never significant. However, an interaction was found between the percentage of concentrate and the time of the asymptote of the cumulative intake profile (parameter A : $P < 0.001$) and the rate of intake (parameter B : $P = 0.01$). Parameters A and B of goats fed the H diet decreased, respectively, from 15.3

to $10.5 \pm 0.72 \text{ g/kg of BW}$ ($P < 0.001$) and from 0.055 to $0.035 \pm 0.0041/\text{min}$ ($P < 0.001$) between wk 4 and 10, whereas these measurements did not change with time for goats fed the L diet ($14.5 \pm 0.72 \text{ g/kg of BW}$ and $0.037 \pm 0.0041/\text{min}$, respectively).

Daily DMI was not influenced by the percentage of concentrate (Table 2). However, an interaction was observed between the percentage of concentrate and time on daily DMI relative to BW (Table 2), with a higher decrease of the daily DMI relative to BW for goats fed the H diet than for goats fed the L diet between wk 4 and 10 (Figure 1a).

Rumen Fermentation Characteristics After Feeding

Rumen pH and $\text{NH}_3\text{-N}$ concentration were lower and the rumen redox potential and soluble carbohydrate concentration were higher for goats fed the H diet than for those fed the L diet (Table 3, Figure 2a and 2b). The percentage of concentrate did not affect total VFA concentration, but goats fed the H diet had lower acetate:propionate ratios and lower proportions of branched-chain VFA (BCVFA, isobutyrate and isovalerate) than goats fed the L diet (Table 3, Figure 2c and 2d).

The interaction between the percentage of concentrate and the time after feeding had an effect on most of the measurements. The decrease after feeding of the ruminal concentration of BCVFA was more marked for goats fed the L diet compared with those fed the H diet (Figure 2d).

The minimal value of pH after feeding was lower and duration of pH below 6.0 was higher in goats fed the H diet compared with those fed the L diet (Table 3, Figure 2a). Initial value of pH was much lower at wk 10 than at wk 4 for H goats ($P < 0.001$). Furthermore, the pH decrease after feeding was higher in wk 4 than in wk 10 for goats fed the H diet ($P < 0.001$) but not for goats fed the L diet (Table 3, Figure 2a).

In Sacco Ruminal Degradability and In Vivo Total-Tract Digestibility

In sacco DM and starch degradability of maize was not affected by the percentage of concentrate (EDDM = $75.9 \pm 0.41\%$; EDS = $82.6 \pm 0.34\%$). The EDDM and EDNDF of grass hay were lower for goats fed the H diet than for goats fed the L diet (Table 4). Results for in sacco ADF degradability of grass hay were the same as the results of in sacco NDF degradability (EDADF = $19.4 \pm 0.88\%$ for the H diet vs. $24.0 \pm 0.88\%$ for the L diet; $P = 0.001$).

The OM total-tract digestibility was higher in goats fed the H diet ($71.0 \pm 1.31\%$) than in those fed the L

Table 2. Effect of the percentage of concentrate on BW, intake, milk yield, milk composition, and energy and protein balance

Item	Diet ¹		SEM	P-value ²		
	L	H		C	W	C × W
Intake and BW						
DMI (kg/d)	2.68	2.98	0.105	0.27	0.02	0.09
DMI (g/kg of BW per day)	42.1	45.7	1.33	0.11	0.01	0.02
BW (kg)	63.0	66.1	1.59	0.01	<0.001	0.72
Milk production and composition						
Raw milk yield (kg/d)	2.95	3.71	0.176	<0.001	<0.001	0.36
3.5% FCM (kg/d)	3.27	3.68	0.157	0.06	<0.001	0.96
Milk yield (g/d)						
Fat	123	128	6.6	0.55	<0.001	0.93
Protein	96	116	4.7	0.004	0.02	0.50
Lactose	137	173	8.9	0.001	<0.001	0.83
Milk content (g/kg)						
Fat	41.9	34.9	2.07	<0.001	<0.001	0.01
Protein	32.5	32.0	0.67	0.43	0.004	0.76
Lactose	46.0	46.7	0.52	0.14	<0.001	0.08
Milk fat:protein ratio	1.28	1.09	0.048	<0.001	<0.001	0.08
Energy and protein calculated balance ³						
NE _L intake (MJ/d)	15.5	20.4	0.87	<0.001	0.13	0.005
NE _L balance (MJ/d)	-0.43	2.62	0.561	<0.001	0.02	0.16
PDIE intake (g of PDI/d)	272	350	13.7	0.001	0.03	0.08
PDIE balance (g of PDI/d)	85	119	8.2	0.03	0.01	0.28

¹L = low percentage of concentrate (n = 7 goats), H = high percentage of concentrate (n = 6 goats).

²C = percentage of concentrate; W = week; C × W = interaction between percentage of concentrate and time.

³PDIE = protein digestible at the level of intestine when energy is limiting.

diet ($65.7 \pm 1.31\%$; $P = 0.003$). Starch digestibility tended to be higher ($98.9 \pm 0.49\%$ for the H diet vs. $97.89 \pm 0.49\%$ for the L diet; $P = 0.07$), whereas NDF and ADF total-tract digestibility were not affected by experimental diets, with means of $56.8 \pm 1.21\%$ and $50.7 \pm 1.83\%$, respectively.

Blood Composition Before and After Feeding

Plasma concentrations of glucose, insulin, BHBA, urea, and osmotic pressure measured after feeding (Table 5) were not affected by the percentage of concentrate. Plasma concentration of NEFA was lower, whereas L-lactate concentration was higher for goats fed the H diet than for those fed the L diet after feeding (Table 5).

Plasma concentrations of insulin, NEFA, BHBA, L-lactate, and osmotic pressure measured before feeding were affected by the percentage of concentrate in the same way as after feeding. Goats fed the H diet had higher plasma concentrations of glucose than those fed the L diet before feeding (3.28 vs. 3.07 ± 0.056 mmol/L, respectively; $P = 0.007$) and lower plasma concentration of urea-N (18.8 vs. 23.1 ± 1.08 mmol/L, respectively; $P = 0.003$). Blood pH and bicarbonate concentration before feeding were not affected by the percentage of concentrate (7.41 ± 0.006 and 27.5 ± 0.54 , respectively).

Values of NEFA before feeding were higher for goats fed the L diet compared with goats fed the H diet (Figure 2e), and the decrease in concentration of NEFA after feeding was higher for goats fed the L diet than for those fed the H diet (Figure 2e). During the trial, NEFA in plasma before feeding decreased over time for goats fed the L diet, whereas it was quite stable across weeks for goats fed the H diet (Figure 1b).

Animal Performance and Milk Composition

Throughout the trial, RMY was higher in goats fed the H diet than in those fed the L diet (Table 2, Figure 1a). Compared with goats fed the L diet, those fed the H diet had lower MFC and fat:protein ratio, and higher protein and lactose yields (Table 2, Figure 1c). An interaction was observed between the percentage of concentrate and time only on MFC (Table 2), with a higher decrease of MFC for goats fed the L diet compared with the H diet (Figure 1c). Calculated net energy balance (NEB) and PDI balance were higher for goats fed the H diet than those fed the L diet (Table 2). The energy balance of goats fed the L diet was negative (Figure 1b).

Compared with goats fed the L diet, those fed the H diet had higher proportions of C8:0, C10:0, C12:0, C14:0, *cis*-12 C18:1, *cis*-13 C18:1, total *trans* C18:1 isomers, *cis*-9, *cis*-12 C18:2, *cis*-9, *trans*-12 and *trans*-

Figure 1. a) DMI relative to BW (—) and raw milk yield (RMY, ----), b) calculated NE_L balance (—) and plasma concentration of NEFA (----), c) milk fat content (MFC, —) and milk lactose content (MLC, ----) of goats fed experimental TMR with a low (○) or high (▲) percentage of concentrate from wk 4 to 10.

11, *cis*-15 C18:2 in milk, and lower proportions of C16:0, C18:0, C20:0, *cis*-9 C16:1, and *cis*-9-C18:1 (Table 6). Odd-chain FA and branched-chain FA were not affected by the percentage of concentrate, except for C13:0, iso-C15:0, and iso-C16:0. Ratios *cis*-9 C14:1/C14:0 to *cis*-9, *trans*-11 C18:2/*trans*-11 C18:1 were not modified by the percentage of concentrate.

DISCUSSION

Intake, Ruminal Measurements, Nutrient Digestibility, and Plasma Metabolites

DMI and Physical Measurements of Rumen.

In our study, daily DMI was not influenced by the per-

centage of concentrate because of high between-goat variability. From a meta-analysis of trials on dairy goats, Sauvant et al. (2007) predicted a mean increase of 100 g/d of DMI per 10% of concentrate when percentage of concentrate of the diet was around 50%. In our trial, the corresponding value was 86 g/d per 10% concentrate.

Considering the cumulative intake profile, 2 periods can be distinguished in our trial. In wk 4, the high percentage of concentrate caused an increase in the rate of intake, due to a lower fill effect of the H diet compared with the L diet in accordance with lower NDF and higher starch contents. At wk 10, animals fed the H diet limited their rate of intake to the same level as

Table 3. Effect of the percentage of concentrate on rumen measurements at 0, 1, 2, 4, and 6 h after the morning feeding in wk 4 and 10

Item ¹	Diet ²					P-value ³				
	L, Wk 4	L, Wk 10	H, Wk 4	H, Wk 10	SEM	C	W	C × W	T	C × T
pH	6.47 ^a	6.35 ^b	6.12 ^c	5.96 ^d	0.062	<0.001	<0.001	0.37	<0.001	<0.001
Initial pH	6.85 ^a	6.74 ^a	6.82 ^{ab}	6.34 ^c	0.010	0.002	<0.001	<0.001	—	—
Minimal pH	6.18 ^a	6.08 ^a	5.62 ^b	5.65 ^b	0.012	<0.001	0.59	0.29	—	—
Amplitude of pH decrease	0.65 ^b	0.65 ^b	1.22 ^a	0.62 ^b	0.013	0.01	0.002	0.002	—	—
Duration of pH <6.0 (min)	18 ^b	35 ^b	182 ^a	178 ^a	4.3	0.004	0.76	0.61	—	—
Redox potential (mV)	−372 ^b	−372 ^b	−352 ^a	−356 ^a	3.6	0.002	0.54	0.53	<0.001	0.003
Osmotic pressure (mOsm/L)	322 ^b	331 ^{ab}	345 ^{ab}	348 ^a	6.8	0.09	0.39	0.73	<0.001	0.002
Soluble carbohydrates (g/L)	1.65 ^{ab}	1.55 ^b	2.50 ^a	2.37 ^a	0.165	0.02	0.52	0.93	<0.001	0.02
Ammonia-N (mmol/L)	8.12 ^b	9.95 ^a	4.62 ^c	5.31 ^c	0.795	0.003	0.02	0.30	<0.001	0.01
Total VFA (mmol/L)	100	102	109	105	2.3	0.19	0.75	0.26	<0.001	0.42
VFA (mol/100 mol)										
Acetate (A)	67.7 ^a	68.5 ^a	63.6 ^b	63.3 ^b	0.94	0.005	0.71	0.42	<0.001	0.01
Propionate (P)	18.8 ^b	18.0 ^b	22.8 ^a	24.1 ^a	1.13	0.04	0.77	0.25	<0.001	0.01
Butyrate	10.6	10.6	11.5	10.9	0.35	0.49	0.46	0.45	0.002	0.11
Isobutyrate	1.00 ^a	0.95 ^a	0.57 ^b	0.43 ^b	0.084	0.002	0.09	0.37	<0.001	0.05
Valerate	1.02 ^{ab}	1.03 ^{ab}	1.07 ^a	0.91 ^b	0.038	0.63	0.02	0.01	<0.001	0.05
Isovalerate	0.62 ^a	0.65 ^a	0.34 ^b	0.22 ^b	0.063	<0.001	0.25	0.09	<0.001	0.005
BCVFA ⁴	1.62 ^a	1.60 ^a	0.91 ^b	0.66 ^b	0.146	<0.001	0.12	0.19	<0.001	0.03
A:P ratio	3.66 ^a	3.87 ^a	2.82 ^b	2.86 ^b	0.179	0.002	0.23	0.41	<0.001	0.37

^{a-d}Within a row, means without a common superscript letter differ ($P < 0.05$).

¹Data on pH were calculated after having described pH data by a third-degree polynomial model as described by Dragomir et al. (2008).

²L = low percentage of concentrate ($n = 7$ goats), H = high percentage of concentrate ($n = 6$ goats).

³C = percentage of concentrate; W = week; T = time after feeding.

⁴BCVFA = branched-chain VFA (isobutyrate + isovalerate).

goats fed the L diet and reduced their DMI. Such an adaptation of intake behavior was observed by Desnoyers et al. (2008b) in goats seeking to avoid subacute ruminal acidosis. Abijaoudé et al. (2000b) reported an increase in the number of secondary meals and DMI during these meals when feeding a high percentage of concentrate. These changes of intake behavior would allow greater salivation and thus a higher production of buffer, which could explain the smaller pH decrease between the onset and the end of the trial for goats fed the H diet. It is also possible that H goats had some type of aversion to the high-concentrate diet after suffering subacute ruminal acidosis (Desnoyers et al., 2009). The H goats reduced their DMI throughout the experiment, resulting in a progressively smaller depression of MFC; however, no significant interaction between the percentage of concentrate and week for RMY and milk lactose contents was observed. However, according to blood pH and bicarbonate concentration, goats in our study were not in metabolic acidosis.

Rumen pH in this study was low compared with other published data on dairy goats fed high percentages of concentrate (Cerrillo et al., 1999), but similar to that observed for lactating goats with high levels of DMI/BW (Santini et al., 1992; Lu, 1993).

Rumen VFA and Consequences on Metabolism. The A:P was comparable to that of lactating goats having a similar level of DMI/BW (Santini et al., 1992). The increase in plasma glucose concentration

before feeding the diet with the high percentage of concentrate probably reflects higher hepatic glucogenesis (Bobe et al., 2004), coherent with the higher propionate proportion observed in our trial. Propionate that escapes from gluconeogenesis can be a precursor for the synthesis of the linear odd-chain FA in the mammary gland from propionyl-CoA and malonyl-CoA (Massart-Leën et al., 1983). This could explain the increase in the proportion in C13:0 in the milk of goats fed the H diet compared with those fed the L diet. However, a large part of the C13:0 also comes from synthesis by rumen bacteria (Vlaeminck et al., 2006).

Ruminal Nitrogen and Metabolism. An increase in nitrogenous concentrate supply generally increases the $\text{NH}_3\text{-N}$ content of rumen juice. However, the opposite was found in the current work, as in Abijaoudé et al. (2000a). As the energy availability in the rumen was probably much higher in the H diet than in the L diet, rumen microbes of H diet fed animals would require more $\text{NH}_3\text{-N}$ to sustain their growth, which would decrease rumen $\text{NH}_3\text{-N}$ concentration, plasma urea, and milk urea. The higher percentage of concentrate decreased the concentrations and the proportions of BCVFA, possibly because of a reduction in catabolism of dietary branched-chain amino acids. The BCVFA (isobutyrate and isovalerate) in the rumen are largely derived from the catabolism of dietary branched-chain amino acids (valine and leucine, respectively; Allison, 1969). As iso-C15:0 and iso-C16:0 are formed from va-

Figure 2. Short-term dynamics of ruminal measurements: a) pH, b) ammonia-N, c) acetate:propionate ratio, d) the proportion of branched-chain VFA, and e) plasma concentrations of NEFA after the morning meal in goats fed experimental TMR with a low (○) or high (▲) percentage of concentrate in wk 4 (dotted line) and 10 (solid line).

Table 4. Effect of the percentage of concentrate on in sacco degradability of DM and NDF when grass hay was the tested ingredient

Item ¹	Diet ²		SEM	P-value
	L	H		
DM				
Soluble: <i>a</i>	19.0	23.7	0.86	<0.001
Degradable: <i>b</i>	51.2	46.0	1.03	0.002
Rate of degradation (%/h)	0.065	0.045	0.0043	<0.001
Effective degradability	45.2	42.8	0.50	0.001
NDF				
Soluble: <i>a</i>	1.03	4.69	1.045	0.06
Degradable: <i>b</i>	59.5	64.0	3.65	0.55
Rate of degradation (%/h)	0.059	0.041	0.0056	0.08
Effective degradability	30.5	27.0	0.70	0.003

¹Data of DM and NDF disappearance were fitted with the nonlinear model proposed by Ørskov and McDonald (1979): Disappearance = $a + b(1 - e^{-ct})$, where *a* is the soluble fraction (% of total DM or NDF), *b* the degradable fraction (% of total DM or NDF), *t* the time of rumen incubation (h), and *c* is the relative rate of degradation of fraction *b* (h⁻¹). Effective degradabilities of DM or NDF were calculated with a particle outflow from the rumen of 0.06 h⁻¹.

²L = low percentage of concentrate (n = 6 goats), H = high percentage of concentrate (n = 6 goats).

line and leucine (Vlaeminck et al., 2006), these iso-FA were also decreased in the rumen and then in the milk.

In Sacco Degradability and In Vivo Digestibility. In sacco degradability of NDF and ADF was lower on the H diet compared with the L diet. The depression of fiber digestion can be related to the reduction in activity of the cellulolytic microbes associated with the decrease in ruminal pH (Santini et al., 1992; Archimède et al., 1997). However, total-tract digestibility of NDF and ADF was not modified by the percentage of concentrate, probably because of the partial substitution of ruminal digestion by intestinal digestion (Archimède et al., 1997).

Plasma NEFA and Energy Balance. Despite higher milk energy output for goats fed the H diet and because of the higher energy content of the H diet, NEB was improved by 209 kcal per 10% of concentrate. In the literature, only Rapetti et al. (1997) observed such an NEB increase per 10% of concentrate. The meta-analysis of Sauvant et al. (2007) suggested a mean NEB

increase of only 119 kcal per 10% of concentrate with similar contents of concentrate. Lower NEB was associated with higher plasma NEFA concentrations of goats fed the L diet. This was expected because plasma NEFA concentration reflects the mobilization of adipose tissue to meet energy requirements (Dunshea et al., 1988).

Milk Production and Milk Composition

In our study, RMY increased by 229 g per 10% of concentrate, whereas Sauvant et al. (2007) predicted a mean RMY increase of 120 g per 10% of concentrate for similar contents of concentrate. That meta-analysis compiled articles with a RMY increase between 36 g (Kawas et al., 1991) and 240 g (Desnoyers et al., 2008a) per 10% of concentrate. These differences may be due to the stage of lactation of goats, their energy status, the nature of the diet, and the distribution mode of the diet (TMR vs. forage and concentrate separated).

Table 5. Effect of the percentage of concentrate on plasma composition measured at 0, 0.5, 1, 1.5, 2, 3, 4, and 6 h after the morning feeding in wk 4 and 10

Item	Diet ¹				SEM	P-value ²				
	L, Wk 4	L, Wk 10	H, Wk 4	H, Wk 10		C	W	C × W	T	C × T
Glucose (mmol/L)	3.23 ^b	3.25 ^{ab}	3.42 ^a	3.32 ^b	0.045	0.14	0.13	0.01	<0.001	0.55
Insulin (nmol/L)	0.085 ^b	0.098 ^{ab}	0.214 ^a	0.196 ^{ab}	0.0349	0.09	0.77	0.07	<0.001	0.06
NEFA (mmol/L)	0.259 ^a	0.156 ^b	0.146 ^b	0.141 ^b	0.0125	<0.001	<0.001	<0.001	<0.001	<0.001
BHBA (mmol/L)	0.427	0.460	0.415	0.420	0.0246	0.57	0.50	0.61	<0.001	<0.001
Urea (mmol of N/L)	24.1 ^a	24.2 ^a	18.1 ^b	18.8 ^{ab}	1.44	0.08	0.59	0.65	<0.001	0.55
L-Lactate (mmol/L)	0.344 ^c	0.440 ^{ab}	0.452 ^b	0.515 ^a	0.0223	0.03	<0.001	0.28	<0.001	0.09
Osmotic pressure (mOsm/L)	300	301	300	302	0.7	0.69	0.06	0.32	<0.001	0.27

^{a-c}Within a row, means without a common superscript letter differ ($P < 0.05$).

¹L = low percentage of concentrate (n = 7 goats), H = high percentage of concentrate (n = 6 goats).

²C = percentage of concentrate; W = week; T = time after feeding.

Table 6. Effect of the percentage of concentrate on the fatty acid profile (% total fatty acids) of milk fat

Item	Diet ¹		SEM	P-value
	L	H		Concentrate
C _{4:0}	1.82	1.74	0.043	0.34
C _{6:0}	2.38	2.50	0.060	0.29
C _{8:0}	2.88	3.22	0.094	0.01
C _{10:0}	9.68	11.30	0.350	0.003
C _{11:0}	0.29	0.34	0.017	0.10
C _{12:0}	3.70	4.88	0.205	<0.001
C _{13:0}	0.14	0.19	0.011	0.02
C _{14:0}	8.97	10.59	0.257	<0.001
<i>iso</i> -C _{14:0}	0.10	0.10	0.007	0.99
<i>cis</i> -9 C _{14:1}	0.13	0.14	0.006	0.24
C _{15:0}	1.01	1.04	0.030	0.57
<i>iso</i> -C _{15:0}	0.22	0.17	0.010	<0.001
<i>anteiso</i> -C _{15:0}	0.33	0.30	0.012	0.17
C _{16:0}	27.95	23.79	0.754	<0.001
<i>iso</i> -C _{16:0}	0.24	0.27	0.007	0.03
<i>cis</i> -9 C _{16:1}	0.48	0.37	0.027	0.05
C _{17:0}	0.70	0.71	0.009	0.78
<i>iso</i> -C _{17:0}	0.47	0.42	0.047	0.65
<i>anteiso</i> -C _{17:0}	0.33	0.34	0.007	0.58
C _{18:0}	9.23	8.07	0.343	0.04
<i>trans</i> -6, <i>trans</i> -7, and <i>trans</i> -8 C _{18:1}	0.30	0.43	0.023	<0.001
<i>trans</i> -9 C _{18:1}	0.29	0.42	0.021	<0.001
<i>trans</i> -10 C _{18:1}	0.38	0.67	0.047	<0.001
<i>trans</i> -11 C _{18:1}	1.38	2.78	0.231	<0.001
<i>trans</i> -12 C _{18:1}	0.34	0.51	0.030	<0.001
<i>cis</i> -6 and <i>trans</i> -13 and <i>trans</i> -14 C _{18:1}	0.23	0.59	0.055	0.01
<i>trans</i> -15 C _{18:1}	0.29	0.33	0.011	0.01
<i>trans</i> -16 C _{18:1}	0.25	0.32	0.013	0.01
<i>cis</i> -9 C _{18:1}	18.51	15.32	0.677	0.01
<i>cis</i> -11 C _{18:1}	0.41	0.46	0.015	0.10
<i>cis</i> -12 C _{18:1}	0.26	0.47	0.041	0.003
<i>cis</i> -13 C _{18:1}	0.08	0.09	0.004	0.02
<i>cis</i> -9, <i>cis</i> -12 C _{18:2}	2.81	3.35	0.116	0.004
<i>cis</i> -9, <i>trans</i> -12 C _{18:2}	0.05	0.06	0.001	0.01
<i>cis</i> -9, <i>trans</i> -11 C _{18:2}	0.65	1.28	0.112	<0.001
<i>trans</i> -11, <i>cis</i> -15 C _{18:2}	0.06	0.09	0.006	0.01
<i>cis</i> -9, <i>cis</i> -12, <i>cis</i> -15 C _{18:3}	0.85	0.78	0.021	0.10
C _{20:0}	0.16	0.13	0.008	0.003
C _{20:4}	0.12	0.11	0.004	0.16
Unidentified fatty acids	1.18	1.28	0.085	0.16
Saturated fatty acids	70.61	69.76	0.673	0.46
Sum of <i>trans</i> C _{18:1} + <i>cis</i> -6 C _{18:1}	3.43	5.96	0.420	<0.001
Monounsaturated fatty acids	23.33	22.78	0.513	0.56
Polyunsaturated fatty acids	4.82	6.03	0.194	0.001
<i>cis</i> -9 C _{14:1} /C _{14:0}	0.01	0.01	0.001	0.54
<i>cis</i> -9 C _{16:1} /C _{16:0}	0.02	0.02	0.001	0.58
<i>cis</i> -9 C _{18:1} /C _{18:0}	2.05	1.92	0.091	0.37
<i>cis</i> -9, <i>trans</i> -11 C _{18:2} /trans-11 C _{18:1}	0.47	0.46	0.013	0.72

¹L = low percentage of concentrate (n = 7 goats), H = high percentage of concentrate (n = 6 goats).

Milk protein yield increased with the higher proportion of concentrate in the diet but MPC was not modified, in agreement with the observations of Rapetti et al. (1997). The greater milk synthesis could be related to the higher microbial protein synthesis in the H diet compared with the L diet.

Feeding high-concentrate diets generally induces low MFC in goats (Sauvant et al., 2007). A decrease of 4.48 g of fat/kg of milk between goats fed the H diet and those fed the L diet was predicted from the relationship

determined by Schmidely and Sauvant (2001) for goats, whereas in the current study the actual decrease was 6.50 g of fat/kg of milk. Because milk fat yield was not modified by the percentage concentrate, the decrease of MFC can be related mainly to a dilution effect.

Feeding high-concentrate diets does not generally modify or increase the proportion of FA with 4 to 8 carbon atoms in milk (Calderon et al., 1984; Ledoux et al., 2002; Andrade and Schmidely, 2006). In goats fed the H diet, the proportions of medium-chain FA (FA with

10 to 16 carbon atoms) in milk increased, except for the proportion of C16:0. Conflicting results have been reported concerning medium-chain FA in dairy goats: C10:0 and C12:0 increased (Andrade and Schmidely, 2006) or were not modified by a higher proportion of concentrate in the diet (Calderon et al., 1984; Ledoux et al., 2002), whereas decreases in C14:0 and C16:0 were also observed by Andrade and Schmidely (2006). Discrepancies between these data and our results may be due to the use of a calcium palm oil salt in the L diet that is rich in C16:0 and *cis*-9 C18:1 and to a lesser extent in *cis*-9, *cis*-12 C18:2. Indeed, mammary synthesis of medium-chain FA is inhibited by dietary C18:0 and C18:1 (Chilliard et al., 1993; Teh et al., 1994), which may explain the low proportion of FA from C10:0 to C14:0 and the high proportion of C16:0 in milk of goats fed the L diet in our study. The increase in the percentage of concentrate in our study decreased the proportion of C18:0, possibly because of higher dietary amounts of this FA in the L diet than in the H diet, and to ruminal hydrogenation conditions probably more saturating for the FA of the L diet than those of the H diet (see below). The proportions of *cis*-9 C16:1 and *cis*-9 C18:1 in milk decreased with increasing percentage of concentrate. These FA partly originate from their plasma uptake and partly from desaturation of C16:0 and C18:0 by mammary Δ^9 -desaturase (Chilliard and Ferlay, 2004). The decrease in the proportions of *cis*-9 C16:1 and *cis*-9 C18:1 was directly linked to the decrease of the proportions of C16:0 and C18:0, because the calculated proxy of Δ^9 -desaturase activity (*cis*-9 C18:1/C18:0) was not modified by the concentrate proportion. The proportions of total *trans*-C18:1 were increased by the percentage of concentrate as already observed in the literature (Calderon et al., 1984; Ledoux et al., 2002; Andrade and Schmidely, 2006). These isomers are intermediary products of ruminal biohydrogenation of the dietary polyunsaturated FA (Glasser et al., 2008). Consequently, ruminal biohydrogenation conditions in goats fed the H diet appear to stay high but would be slightly less efficient than for goats fed the L diet. These differences probably arise from changes in rumen microbial populations (Kaufmann et al., 1980) associated with the lower ruminal pH on the H diet. In this context, cellulolytic bacteria seem to be the most active in the ruminal biohydrogenation process (Harfoot and Hazlewood, 1997). Despite the increase of *trans*-C18:1 isomers with the H diet, no modification of the proportion in total *trans*-C18:1 was noticed in our study, and notably no shift from *trans*-11 C18:1 to *trans*-10 C18:1 was observed. Further, the isomer *trans*-10, *cis*-12 C18:2 was not detected. Relative to cows, goats are less likely to produce *trans*-10 C18:1 and *trans*-10, *cis*-12 C18:2. They are also less sensitive to the antilipogenic activ-

ity of *trans*-10, *cis*-12 C18:2 (Shingfield et al., 2010). The *trans*-11 C18:1 is the major *trans* C18:1 isomer, which explains why *cis*-9, *trans*-11 C18:2 was the major conjugated linoleic acid, due to the action of the Δ^9 -desaturase of mammary gland.

CONCLUSIONS

This study evaluated the effect of high-concentrate diets on dairy goats. The results were consistent with previous reports in goats and dairy cows. This work extended the current information by collecting a large number of simultaneous measurements for a relatively long time. Such a study is essential to generate data for building or improving empirical and mechanistic models aimed at predicting the response to dietary change at the digestive, metabolic, and mammary levels.

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