Effects of a Nonforage Diet on Milk Production, Energy and Nitrogen Metabolism in Dairy Goats throughout Lactation

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ABSTRACT

The objective of the experiment was to compare a silage-based control diet (C) with a totally forage-free diet (NF) in dairy goats throughout lactation in terms of animal performance and energy utilization.

Eight Saanen goats were divided into two groups and fed diet C or diet NF (commercial blend) which included sunflower meal, cassava, coconut meal and whole cottonseeds as the main ingredients and was characterized by a small particle size and a high crude protein content. In early, mid and late lactation (44, 100 and 219 DIM) the goats were individually tested for DM intake (DMI), digestibility, milk yield and composition, milk renneting properties, rumen and plasma parameters and nitrogen and energy utilization (open circuit respiration chambers).

During early and mid lactation, the NF fed goats had a very high DMI: 2946 and 2915 g/d, respectively. Nevertheless, milk yield was similar for the two treatments: 4369 vs. 4342 and 3882

1   vs. 3841 g/d, for diets C and NF, during the first and second period, respectively. Milk fat content

2   was not statistically different between the two diets. The protein content and rheological

3   parameters were similar for the two diets but the NPN and milk urea level of treatment NF were

4   significantly higher than the control. Rumen ammonia and plasma urea nitrogen were also

5   significantly increased by diet NF, due to its high protein content. Plasma glucose, β-

6   hydroxybutyrate and non-esterified fatty acids and rumen volatile fatty acids were not influenced

7   by dietary treatment.

8   Diet NF significantly decreased energy digestibility (74.5 vs. 65.8%, on average for the three

9   stages of lactation, for C and NF respectively) and had a significantly lower metabolizability

10   (metabolizable energy/intake energy) (66.6 vs 58.0%, on average); however, the efficiency of

11   utilization of ME was unaffected by the diet.

12   In conclusion, goats could be fed a forage-free diet during the entire lactation without detrimental

13   effect on their health and productive performance.

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15   (**Key words** : goat, milk, nonforage diet, energy metabolism)

16

17   **Abbreviation key**: **ADL** = acid detergent lignin, **C** = control diet, **HP** = heat production, k_l =

18   efficiency of utilization of ME for lactation, **ME** = metabolizable energy, **MUN** = milk urea

19   nitrogen, **NF** = nonforage diet, **NFC** = non-fibrous carbohydrates, **PUN** = plasma urea nitrogen.

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21   **INTRODUCTION**

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Dietary fiber plays a fundamental role in ruminants to maximize DM intake and stimulate chewing activity and rumen fermentation. In particular, NDF is defined as "effective" when it ensures a good chewing activity, maintaining a satisfactory milk fat content and FCM yield (Grant, 1997). This role of fiber is strongly influenced by the dimensions of the feed particles and their retention time in the rumen (Woodford and Murphy, 1988).

Recently, there has been increased interest in by-products in partial substitution of traditional feedstuffs in ruminant feeding. From a nutritional point of view, by-products are included in the ration to supply energy and protein, but are often also characterized by a high fiber content. The fiber of by-products has different physical and chemical properties from forage NDF (Zhu et al., 1997); in particular, its particles have small dimensions and a high density (Firkins, 1997). However, many experiments have shown that a partial substitution in the diet of forage fiber with by-product fiber does not negatively affect rumen activity or milk fat content (Zhu et al., 1997; Grant, 1997).

Colenbrander et al. (1991) demonstrated that reducing the size of alfalfa silage particles decreased the chewing activity but did not change milk yield or composition.

Sheep and, even more so, goats are the ruminant species most able to adapt to diets with a high content of low quality fiber; moreover, they seem to be less sensitive to the length of fiber particles (Sanz Sampelayo et al., 1997; Lanza et al., 1996).

Some work has shown that milk fat content in the goat is not necessarily decreased by a reduction of the dietary forage fiber (Rapetti et al., 1995) or by the reduction of the fiber particle size (Sanz Sampelayo et al., 1998), but it is more influenced by energy intake (Morand-Fehr et al., 1991).

Reducing forage particle size increases forage DM intake, particularly if forage quality is poor, due to a shorter retention time of the particles in the rumen (Woodford and Murphy, 1988), but

simultaneously the higher turn-over decreases the energy digestibility of the forage because of the lack of time available for fiber digestion. On the other hand, van der Honing (1975) found that, in comparison with cows fed long forage, cows fed pelleted forage compensated for the higher fecal energy losses with lower methane production and heat expenditure.

The objective of the present work was to compare a diet based on silage with a diet totally free of forage in lactating goats. Milk production, energy and nitrogen utilization, rumen fermentation parameters and some plasma metabolites were recorded at the beginning, middle and end of lactation.

MATERIAL AND METHODS

Animals and Diets

Eight second parity Saanen goats with similar kidding date and 150-d milk yield of the previous lactation, were assigned randomly to one of the two following dietary treatments: a silage-based forage diet (control, **C**) and a nonforage diet (test, **NF**).

Each group of four goats was fed its own assigned diet throughout the entire lactation, after a gradual adaptation during the last 20 days of the dry period. Diet C was balanced to meet the requirements for lactating goats according to Morand-Fehr and Sauvant (1988) and AFRC (1998) for calcium and phosphorus. Diet NF consisted of a commercial blend of raw materials.

The composition and characteristics of the two diets are reported in Table 1. There is a great difference between the two diets in terms of DM, CP, ADF, acid detergent lignin (**ADL**) and non-fibrous carbohydrates (**NFC**) content.

The diets were offered for ad libitum intake allowing for about 5% orts twice daily at 0730 and 1830h. Goats were milked twice daily at 0800 and 1900h, by machine.

The trial was divided into three experimental periods of 8 d during early, mid and late lactation with, on average, 46 and 42, 102 and 98, 221 and 217 DIM for treatments C and NF, respectively. The average BW of the control and the test goats during the first, the second and the third experimental period were 52.0 and 47.5, 57.8 and 53.9, 61.1 and 58.6 kg, respectively.

The goats were confined in two free stalls on wheat straw bedding. During each experimental period the animals were allocated to individual metabolic cages to determine apparent digestibility (8 days of collection). During the collection period the goats were confined, for 4 d, in pairs, in a respiration chamber in order to measure three 24-h cycles of respiratory exchanges. Heat production was thus computed indirectly, with an open circuit respiration chamber system described by Crovetto (1984). Particularly, daily oxygen consumption and carbon dioxide and methane production were determined measuring the volume of air circulated in the system in 24 h (and referred to standard conditions) and multiplying it by the difference between the relative concentrations of the gases measured continuously in the ingoing and in the outgoing air. The goats were adapted to metabolic cages for 2 wk weeks before each experimental period and weighed before and after each digestibility trial.

Experimental Procedures and Laboratory Analyses

Diets, orts and feces samples for each goat were weighed and sampled daily during the three experimental periods, pooled by period and animal and frozen for analyses. Samples were dried at 55°C in a forced air-oven and ground through a 1-mm screen in a mill (Pulverisette-14,

FRITSCH, Idar-Oberstein, Germany), prior to analysis. The dried diets were manually sieved with a shaker with eight screens (UNI series) to determine their particle distributions

Dry samples were analyzed for DM, ash, OM, N, and ether extract according to the Italian Scientific Association for Animal Production recommendations (ASPA, Commissione Valutazione degli Alimenti, 1980). The NDF, ADF, and ADL were determined sequentially according to the procedure of Van Soest et al. (1991). Carbon content was assessed by means of an automatic elemental analyzer (NC 2100 Soil Analyzer, ThermoQuest, Milan, Italy).

Urine was collected daily in a plastic bottle containing an adequate amount of a solution of H_2SO_4 10% (v/v) to acidify the urine of each goat. Samples of acidified urine were used for N and energy determinations. The determination of chemically bound CO_2 (required to calculate total CO_2 production and C balance) was performed on urine samples mixed with formalin (20 ml/l urine) and collected at the end of each period.

Immediately after milking, the individual milk yield was weighed and, after mixing, a sample of 10% was put in a bottle with 20 mg of potassium dichromate as a preservative and stored at 4°C prior to analyses.

The C content of the urine and milk samples was determined immediately after the calorimetric determination, by passing the gas stream from the bomb calorimeter through a suitable set of absorption tubes to bind the CO_2 (Nijkamp, 1969, 1971).

The gross energy of all samples was determined with an adiabatic calorimeter (IKA® 4000, Staufen, Germany); urine and milk samples were placed in polyethylene bags, freeze-dried and then burnt in the calorimeter (Nijkamp, 1969, 1971). Milk energy secretion was also corrected in function of retained energy as follows: corrected milk energy secretion = milk energy + (1.05 positive retained energy) (AFRC, 1998).

Total N, NPN, casein, and fat content (Gerber method) of milk was determined according to the Italian Scientific Association for Animal Production recommendations (ASPA, 1995). Particularly, NPN was determined by precipitation of milk protein by addition of a 12% TCA-solution and subsequent filtration of the milk protein precipitated and determination of the N content. A similar procedure was followed for the casein determination, with an acetic-acetate buffer.

Milk samples were also analyzed for acidity, pH, lactose (Milkoscan 605, Foss, Hillerod, Denmark), SCC (Fossomatic 360, Foss, Hillerod, Denmark) expressed as a linear score ($LS=\log_2(SCC/12,500)$) and urea (**MUN**, milk urea nitrogen) (CL10, Eurochem, Italy).

The evaluation of the milk renneting properties was determined utilizing a dynamic rheological instrument (Tromb-elastograph, Hellige, Freiburg in Breisgau, Germany) according to the method of Tarodo De La Fuente et al. (1969). Three rheological parameters were considered: coagulation time (r), renneting time (k_{10}: time to reach the curd firmness corresponding to a distance of 10 mm between the two traces on the photographic chart), and curd firmness (E_{30}: curd firmness 30 min after the coagulation time).

Total heat production (**HP**) was determined by indirect calorimetry from the respiration exchanges using Brouwer's (1965) equation: HP (kJ/d) = 16.18 O_2 + 5.02 CO_2 - 5.99 N - 2.17 CH_4, where gas volumes (L/d) are expressed at standard conditions and N (g/d) is the urinary nitrogen. The requirement for metabolizable energy for maintenance was assumed to be 438 $kJ/BW^{0.75}$ (AFRC, 1998).

At the end of the three experimental periods, blood and rumen fluid samples were collected from each goat.

Jugular blood samples were taken before the morning feeding and 4 h after feeding. Blood was sampled in 10-ml tubes treated with EDTA or Li-eparine, immediately centrifuged for plasma separation and stored at $-20°C$. Plasma samples with EDTA were used for determination of glucose (by an enzymatic-colorimetric method Peridochrom®Glucose, Roche, Milan, Italy) and β-hydroxybutyrate (BHBA) (β-hydroxybutyrate, Sigma Diagnostics, St. Louis, MO, USA), samples with Li-eparine for non esterefied fatty acids (NEFA) (NEFA Quick "BMY" Sigma Diagnostics, St. Louis, MO, USA) and urea (**PUN**, plasma urea nitrogen) (Urea Nitrogen 535-A, Sigma Diagnostics, St. Louis, MO, USA).

Rumen fluid was sampled by stomach tube before the morning feeding and 4 h and 7 h after feeding. Samples were analyzed for pH, $N-NH_3$ (by direct titration with the Kjeltec Auto 1030 Analyzer, Höganäs, Sweden) and VFA using a gas chromatograph (Carlo Erba 5300 Mega Series, Milan, Italy) with a 0.32-mm i.d. column that was 25 m in length and packed with Fused Silicia and Mega Acid (Mega, Milan, Italy) as the stationary phase. The carrier gas was N_2 at 50 KPa. Injector and flame ionization detector temperatures were $180°C$ and $210°C$, respectively. The temperature was programmed from $110°C$ to $180°C$ at $10°C$/min.

Statistical Analyses

Data were statistically analyzed using the Mixed Procedure of SAS (1996) with the repeated statement (Littell et al., 1998), using the model

$$Y_{ijk} = \mu + T_i + G_{ij} + P_k + (T \times P)_{ik} + e_{ijk}$$

where

Y_{ijk} = response at time k on goat j in treatment group i;

μ = overall mean;

1   T_i = fixed effect of treatment (i = C, NF);

2   G_{ij} = random effect of goat j in treatment group i;

3   P_k = fixed effect of time k (k = period 1, period 2, period 3);

4      $(T \times P)_{ik}$ = fixed interaction effect of treatment i with time k;

5   e_{ijk} = random error at time k on animal j in treatment i.

6 The compound symmetric covariance structure using the repeated statement was used in the

7 Mixed Procedure because it provided the best fit according to the Schwarz Bayesian criterion

8 (Littell et al. 1998).

9 In the statistical analysis of milk production the daily milk production of the previous standard

10 lactation was tested as covariate, but it was not considered in the model because statistically not

11 significant. The statistical analyses of rumen fermentation parameters and blood metabolites

12 were performed using the average value of the different sampling time.

13 All results are reported as least squares means.

14

15   **RESULTS AND DISCUSSION**

16

17 **Diets, feed intake and digestibility**

18 Considering the particle size (Figure 1) for diets C and NF we registered a proportion of 39.5 and

19 22.6% of 4 mm and greater particles and 37.0 and 51.2% of 0.75 mm and smaller particles,

20 respectively. The biggest particles in diet NF consisted of cassava slices and whole cottonseeds.

21 As previously stated (Table 1), diets C and NF differed substantially in several parameters.

22 DM intake ($g/BW^{0.75}$) (Table 2) was increased by NF treatment in periods I (135 vs. 164, $P <$

23 0.05) and II (126 vs. 147, $P < 0.05$). Comparing actual DMI (g/d) with the data predicted from the

equation proposed by Sauvant et al. (1991) which takes into account the milk yield and the

bodyweight, the actual DMI for diet NF, in the first two periods, was significantly higher (+21%

on average, $P < 0.01$). The higher feed intake registered with the NF diet can presumably be

ascribed to the lower retention time of this diet in the gastrointestinal tract, because of its small

bulk-effect and the low digestibility of its fibrous components (van der Honing, 1975).

As expected, the goats fed the NF diet had a significantly higher water intake to compensate for

the lower moisture content of this diet in comparison with the control.

Apparent digestibility was almost always significantly lower (with the exception of ether exctract

and NFC) for diet NF in comparison with the control. A possible explanation for the higher

digestibility of the ether extract in the NF diet is that the ether extract of diet NF had a higher

proportion of highly digestible lipids (triglycerides) in comparison with diet C. Nitrogen

digestibility was not significantly decreased in the NF diet. The ADF was digested to a much

lower extent in diet NF than diet C, and it appeared to be the main factor responsible for the

significant decrease of DM and OM digestibility in the nonforage diet. The reduction of DM

digestibility with increasing ADF content in the diet for lactating goats is confirmed by Santini et

al. (1992).

We also calculated the digestibility of OM in the two diets from the digestibility coefficients of

the single feeds tabulated by Andrieu et al. (1988). In comparison with the values obtained from

this method, the experimental data were slightly lower for diet C (78.9 vs. 75.6%, for tabulated

and experimental mean values) and similar for diet NF (66.1 vs. 67.1%). This suggests that: 1) the

decrease of OM digestibility in the control diet could be attributed to the higher feed intake and

rumen turn-over of our goats as compared to the wethers used for the digestibility trials by INRA

1 and 2) OM digestibility of diet NF was mainly limited by the nature of the fiber rather than by the

2 level of feed intake.

3

4 **Energy and nitrogen utilization**

5 The daily energy balances of the goats are summarized in Table 3. In comparison with diet C, diet

6 NF had a significantly higher energy intake (because of the higher DM intake), but concomitantly

7 higher fecal energy losses: in fact, energy digestibility was 7-10 percentage points lower than the

8 control. Urine energy losses were significantly higher in treatment NF, due to the higher CP

9 content of this diet. In contrast, when expressed as a percentage of the gross energy intake,

10 methane production of diet C diet was higher in the first two periods: this result can be related to

11 the higher content of digestible fiber in diet C in comparison to diet NF. The metabolizable

12 energy (**ME**) intake of the two diets was similar, but considering ME as a proportion of the gross

13 energy intake (metabolizability = q), the NF treatment had significantly lower values (on average:

14 66.6 vs. 58.0%). This is consistent with the findings of van der Honing (1975) who registered q

15 values of rations with pelleted forage 8-9 percentage points lower than rations with long forage.

16 The respiratory quotients obtained in the experiment for C and NF treatments in periods I, II and

17 III were respectively: 1.05 vs. 1.03; 1.09 vs. 1.09; 1.10 vs. 1.09. They confirm the values

18 registered in previous experiments (Crovetto et al., 1994) for mid and late lactation, while the

19 lower values of early lactation are consistent with the lower body energy retention.

20 Considering HP as a percentage of the gross energy intake, diet NF determined lower heat

21 expenditure by the animals (on average: 36.4 vs. 31.2%). This is likely to be ascribed, on one

22 hand, to the lower energy cost of chewing for diet NF, due to its smaller average particle size and,

23 on the other hand, to the higher proportion of ME from fats as compared to diet C. Lachica et al.

(1994) found that the energy cost of eating accounted for 1-5% of the ME ingested. However, the lower heat production of diet NF becomes negligible if one considers this parameter as a proportion of the ME.

Milk energy, retained energy and milk energy corrected were similar in the two treatments.

Table 3 also reports the energy content of the two diets. ME contents were higher in diet C as compared to diet NF. The efficiency of utilization of ME for milk production (**k_l**) was similar in the two treatments and in agreement with that obtained by Aguilera et al. (1990) with Granadina goats. In the third period kl increased considerably, but this is presumably due to the fact that the ME requirement for maintenance assumed probably overestimated, at this stage of lactation, the real maintenance requirement of the animals. The lower maintenance requirement of the animals fed the NF diet in comparison with control, is counterbalanced by the negative influence that the lower digestibility and metabolizability of this diet exerts on k_l. It is in fact well known that k_l decreases with decreasing q values.

The carbon balance of the animals during the experiment (Table 4) show the same trend during lactation and the same differences between treatments as observed for energy: in particular, diet NF had a higher intake and feces/urine excretion, while no significant differences could be seen for methane, carbon dioxide, milk carbon or in terms of carbon retained in the body tissues.

Considering the nitrogen balance (Table 4), diet NF, due to its higher nitrogen content in comparison with the control, led to a greater N intake, but concomitantly higher fecal and urinary losses; as a result the two diets, despite the different protein content, gave similar milk N yield and N retention, as found by Badamana and Sutton (1992).

Milk production

Table 5 reports the main productive results of the goats in the experiment. Raw milk yield was rather high, especially in the first period (over 4.3 kg/d) and did not differ significantly between treatments. This is consistent with the results obtained by Sanz Sampelayo et al. (1998) in Granadina goats fed long or pelleted alfalfa hay and with those of Lanza et al. (1996) in sheep fed traditional or complete, pelleted diets.

Milk fat content was not statistically different between the two diets. However, it has to be underlined the high absolute values obtained with treatment NF, particularly if one considers that the diet was totally forage-free and with a small average particle size. This result confirms the findings of previous work (Lanza et al., 1996; Sanz Sampelayo et al., 1998) where diets with totally pelleted forages increased the milk fat percentage as compared to more traditional diets. In our case, the increase in milk fat could at least partially be explained by the higher fat content of the NF diet (3.2 vs. 5.6%, on DM).

Milk protein content was not statistically different between treatments. In the first period of the experiment, NF diet registered a higher milk NPN. This should probably be ascribed to the higher N content of the NF diet in comparison with the control. In fact, the milk urea content was strongly increased ($P < 0.001$) by NF treatment throughout the trial.

Considering the rheological properties, the data obtained fit with the trend described for these parameters during lactation by Coulon (1994) and indicate that both milks were suitable for cheese making. In particular, NF treatment did not decrease the milk clotting aptitude. These results are important since most goat milk is destined for cheese production.

Rumen and plasma parameters

The data reported in Table 6 show that diet NF determined a significant decrease of rumen pH in all periods. However, the average rumen pH caused by diet NF never fell below 6.2, a value which can be considered sufficiently high to maintain normal rumen fermentation. Ammonia nitrogen was the only parameter significantly higher in diet NF in comparison with diet C throughout lactation, due to its higher protein content; the data registered for the control diet are in agreement with those obtained in other research (Sahlu et al., 1993).

Considering the trend for some rumen parameters at 0-4-7 hours from feeding (Figure 2) it can be noticed that acetate and propionate increased after feeding, as expected, while pH and ammonia tended to decrease immediately after feeding and then to rise again, in agreement with Badamana and Sutton (1992); in particular, NF diet always had lower pH values and higher values for ammonia, as compared to C.

The blood parameters (Table 6) indicate that the two diets provided enough energy to the animals for their production level and consequently the values of the energy indicators (glucose, BHBA and NEFA) were in a normal range, consistent with those obtained in other experiments (Giesecke, 1983; Lindsay and Pethick, 1983). On the other hand, the PUN content in animals receiving diet NF was always significantly higher than control.

For both diets we made a regression between PUN and MUN. The equations and the consequent lines obtained are reported in Figure 3. As already stated, diet NF had higher values for both parameters, because of its higher nitrogen content. As can be seen from the figure, the slope of the two regression lines was similar; this indicates that, independently of the absolute values, for a given increment of PUN there was a rather constant increase in the MUN value. In terms of the

accuracy of the prediction of MUN from PUN, the rather low r^2 values (0.45-0.58) could be explained by the limited number of data available.

CONCLUSIONS

The data obtained indicated that the goats on experiment tolerated a nonforage diet with a high protein content throughout lactation (8 months) with no negative effects on milk yield, composition or the milk renneting properties. It is presumable that a nonforage diet with an adequate protein content could also be utilized successfully, with the advantage of a lower environmental impact.

The NF diet, despite its high fiber content, determined very high feed intakes probably because of the small particle size and the lack of "long" forage fiber. The higher content of ADF and ADL decreased energy digestibility and metabolizability of diet NF in comparison with control, but the efficiency of ME utilization was similar in the two diets.

The NF diet decreased rumen pH, but did not significantly change the VFA production.

In conclusion, a nonforage diet can be utilized in lactating goats, since it permits similar performance to a traditional ration, but its economic convenience and the sustainability of this choice has to be evaluated.

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4

1

LEGENDS

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3

4   Figure 1. Particle distribution of the two experimental diets: ☐ diet C; ■ diet NF

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6   Figure 2. Rumen fluid parameters of the goats fed the two experimental diets: —O— diet C; - -

7   ■- -   diet NF

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9   Figure 3. Relationship between milk urea level (MUN) and plasma urea level (PUN) of the two

10   groups of goats: O diet C; ■   diet NF.

11   Diet C: 1.126 PUN + 10.782; $r^2 = 0.58$

12   Diet NF: 1.196 PUN + 22.655; $r^2 = 0.45$

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