Forage of Different Physical Forms in the Diets of Lactating Granadina Goats: Nutrient Digestibility and Milk Production and Composition[1]

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ABSTRACT

To determine whether the energy balance of goats or characteristics of the diet consumed were the principal factors that determined milk production, feeding and digestion trials were carried out using two groups of 5 Granadina goats. The concentrate fraction of both diets was the same, but the forage fraction of the diets differed. In diet 1, the forage was in the form of long alfalfa hay, and, in diet 2, forage was in the form of pelleted alfalfa. Intake and the forage to concentrate ratio of the two diets were not significantly different, although diet 2 was more digestible. The amount of fat and protein in the milk depended on energy intake and not on dietary treatment. The milk protein of goats fed diet 2 was higher in casein. No sensible differences were noted in the fatty acid composition of the milk. Nitrogen and metabolizable energy utilization for milk production was greater for goats fed diet 2. According to the results obtained, it would seem advantageous to use pelleted alfalfa rather than alfalfa hay in the diets of goats.
(**Key words**: physical form of fiber, nutrient utilization, milk production, lactating goats)

Abbreviation key: **ME** = metabolizable energy.

INTRODUCTION

Ruminal VFA do not become part of a common pool of energy substrate but are instead metabolized through characteristic pathways and, in the case of certain VFA, have specific effects on milk composition. Therefore, the influence of diet on milk production may depend more on fermentation balance and end products than on the content of digestible or metabolizable energy (**ME**) (28).

Physicochemical characteristics of a diet can cause changes in the composition of milk produced by changing the fermentation pattern in the rumen. Changes in the diet that lead to a decrease in the production of acetate and butyrate, the principal precursors of fat synthesis in the mammary gland, can induce a decrease in the fat content of milk (28). Various results (5, 17, 18) from other experiments using goats suggest that the effect described previously also can be observed in goats. Other results (3, 15) suggest that the goat is less sensitive than is the cow and that such changes in the diet are less likely to be reflected in decreases in milk fat content. Other researchers (6, 7, 26) have indicated that milk production and composition are more dependent on the energy balance of the animal than on the composition of the diet.

Because all caprine milk in Spain is used to produce a variety of milk products, especially cheese, particular interest has been expressed in the formulation of diets that yield a product that has optimal nutritional quality (less fat with different fatty acid composition) and use in manufacturing (more coagulable protein). Murphy (19) indicated that changes in the physical form of dietary fiber can lead to changes in milk composition. When sources of dietary fiber are pelleted, fat content may be decreased and the protein content in milk may be increased because the ruminal fermentation time is reduced (24). In the present study, results are presented from experiments on Granadina goats that were fed diets containing either long alfalfa hay or pelleted alfalfa. The objective was to determine whether, in the animal and breed used, the energy balance of the goat or the characteristics of the diet were the more important factors to determine

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the composition and production of milk. In addition to milk production and composition, the digestibility and the efficiency of utilization of the diets for milk production were examined.

MATERIALS AND METHODS

Experimental Design

Ten goats of the Granadina breed, midway through second lactation, were divided into two equal groups based on BW and milk production. Goats were fed the experimental diets for 1 mo before the start of the experiment. The goats were then housed individually in crates for the next 19 d. Every goat received a daily ration consisting of 1.0 kg of forage and 1.0 kg of concentrate; the specific N and energy requirements of this species and breed were considered in the dietary formulation (1). Amounts were sufficient to allow daily milk production of up to 2 kg per goat. In diet 1, the forage fraction consisted of long alfalfa hay. In diet 2, the forage fraction consisted of chopped (particle size, 3 to 4 cm) alfalfa that was pelleted. The concentrate fraction consisted of 360 g/kg of oats, 360 g/kg of corn, 240 g/kg of broad beans, and 40 g/kg of a mineral and vitamin mixture. The composition of the mineral and vitamin mixture was designed to satisfy especially the Ca and P requirements of the goat (20). The mineral and vitamin mixture supplied 2.32 g of Ca, 6.84 g of P, 10.0 g of ClNa, 0.92 g of Fe, 0.12 g of Cu, 0.60 g of Zn, 0.48 g of Mn, 1.20 g of Mg, 0.02 g of Co, 1,333,333 IU of vitamin A, 2,080,000 IU of vitamin D_3, 520 IU of vitamin E, 0.32 g of nicotinic acid, and 0.16 g of vitamins B_1 + B_6 + B_{12} per kg of concentrate mixture.

The first 15 d of the experimental period were for adaptation, and the last 4 d constituted the principal trial period. At 0900 h every day, once the orts from the ration that was offered the previous day had been collected, the goats were hand-milked. Subsequently, the daily rations were distributed. Water was available at all times.

After milking, the goats were weighed on the 1st, 15th, and 19th of the experimental period. Feed intake and milk production were monitored daily. During the 4 d of the principal experimental period, a digestion trial was performed. Feces were collected daily to determine the digestibility of the diets.

Measurements and Analyses

Samples of the forage, concentrate, and orts were collected to determine the composition of the diet fed and of that consumed. Aliquots of the fecal samples taken during the digestion trial were frozen at –20°C until analysis. Similarly, samples of milk with no added preservatives were stored at –30°C until analysis.

The DM and N contents of the samples of the feedstuffs, orts, feces, and milk, as well as milk fat, were analyzed in fresh samples. All other analyses were performed on dried samples. The DM of the feedstuffs was determined by oven-drying at 100 ± 2°C for 24 h and that of the feces and milk was carried out by lyophilization. The N contents of the feedstuffs, orts, feces, and milk were measured using the Kjeldahl method (2). The results were converted to CP by multiplying N by a factor of 6.25 for the feedstuffs and feces and by 6.38 for milk. The NDF, ADF, and acid detergent lignin contents of the feedstuffs and orts were determined using the method of Goering and Van Soest (13). The fat content of the milk was measured by the Gerber method (21), and the fat content of the feedstuffs and feces was measured by extraction with petroleum ether (boiling point, 40 to 60°C). The ash content of the feedstuffs, feces, and milk was determined by incineration in an electric muffle furnace at 550°C. Milk lactose was calculated as the difference between the amount of OM and CP plus fat. Finally, the energy content of the samples was determined by adiabatic bomb calorimetry. Protein fractions were analyzed by means of SDS-PAGE using PhastSystem™ electrophoresis (Pharmacia, Uppsala, Sweden). The SDS-PAGE was performed on 20% homogeneous precast PhastGels™, in accordance with the instructions of the manufacturer (file no. 110; Pharmacia). The gels were stained automatically in the development unit of PhastSystem™ following fast staining with Coomassie blue (file no. 200; Pharmacia). Band densities on SDS gels were quantified. The gels were scanned using a Bioimage analyzer (3CX' Bioimage and visage; Millipore Corp., Bedford, MA) according to the Whole Band Analysis 3.2 Program (30). The standards used were molecular markers (Pharmacia), phosphorylase B (94 kDa), albumin (64 kDa), ovoalbumin (43 kDa), carbonicanhydrase (30 kDa), trypsine inhibitor (20.1 kDa), and lactalbumin (14.4 kDa). Densitometric peak areas from different caseins and from different whey protein fractions were converted to percentages of the total casein peak area or of the total whey protein peak area. To determine the fatty acid composition of the milk fat, the fatty acid methyl esters were separated on an autosystem gas chromatograph (Perkin-Elmer Corp., Norwalk, CT) with a SP-2330 capillary column (60 m × 0.032 mm i.d.; Supelco, Bellefonte, PA) equipped with a flame ionization detector. The temperature was programmed from 60 to 70°C at 2°C/min and from 70 to 230°C at 20°C/min. The carrier gas was He. Injector and detector temperatures were 230 and 250°C, respectively.

The model accounted for variation caused by the physical form of the forage. The results were submitted to an ANOVA in accordance with the general linear models procedure of SAS (25). Based on ANOVA, digestible energy intake was not affected by diet and was considered independent of the diet (27). The effect of digestible energy intake on milk production and composition (milk DM, protein, fat, lactose, and energy concentration) was used as a covariate in the model. When the effect of covariate factor was not significant ($P > 0.05$) the least squares means were calculated from the model omitting this term (27).

Tables report mean values, residual standard deviations (square root of the error mean square) and the level of significance of the effects.

RESULTS AND DISCUSSION

Feeding Behavior of the Goats: Digestive Utilization of the Diets

From the composition of the forage and concentrate fractions of the diets and of the orts, the composition of the diet consumed was determined (Table 1). Forage to concentrate ratios and DMI are also shown in Table 1. No significant differences were detected between diets for any of these values except for DM content ($P \leq 0.05$).

The digestibilities of fat, NDF, and digestible energy were higher ($P \leq 0.05$) for diet 2 than for diet 1 (Table 2).

The most important determinants of digestibility of the diets by goats are those related to chemical composition (9); neither the amount of intake (10) nor the resulting milk production had any significant effect (11). In the present study, the composition of the diets consumed, as well as the milk production obtained from the goats fed both diets, were fairly similar. At the same time, physical form of the diet can affect digestibility. Thus, pelleting can sometimes increase digestibility values for most nutrients (4, 14, 22, 23). Furthermore, Giger et al. (8) found that an interaction between forage and concentrate fractions occurs many times in goats, depending on the nature of forages in the diet. Such an interaction might have caused the differences in the digestibilities of the diets detected here.

N and Energy Utilization for Milk Production

Table 3 shows the BW values and data regarding N utilization. The N available for production was calculated as the difference between the N ingested and the N necessary for maintenance. The N required for maintenance was estimated (1). From these values, the ratios between the N in milk and that ingested or available for production were calculated. The BW values were similar between the groups of goats fed the two diets. The amount of N ingested, as well as

TABLE 1. Forage to concentrate ratios, DMI, and chemical composition of the consumed diets.

	Diet[1]			
	1	2	RSD[2]	P
Forage/concentrate, %/%	44/56	49/51	0	NS[3]
DMI, g of DM/kg$^{0.75}$ per d	74.0	64.1	17.0	NS
Chemical composition				
DM, g/kg	890.3	874.5	3.8	**
OM, g/kg of DM	934.4	928.6	18.8	NS
CP, g/kg of DM	190.3	178.2	12.6	NS
Ether extract, g/kg of DM	25.4	30.3	4.3	NS
NDF, g/kg of DM	378.6	367.7	30.0	NS
ADF, g/kg of DM	211.2	187.6	29.5	NS
ADL,[4] g/kg of DM	41.1	37.9	9.1	NS

[1]The forage fraction of diet 1 consisted of long fiber alfalfa hay; the forage fraction of diet 2 consisted of pelleted alfalfa.

[2]Residual standard deviation.

[3]$P > 0.05$.

[4]Acid detergent lignin.

**$P \leq 0.01$.

TABLE 2. Digestibility coefficients and digestible energy content of the diets.

	Diet[1]			
Digestibility	1	2	RSD[2]	P
	— (% of DM) —			
DM	73.2	76.4	4.3	NS[3]
OM	75.1	79.3	3.6	NS
CP	79.5	79.4	5.5	NS
Fat	80.1	92.0	3.0	***
NDF	58.2	64.7	4.0	*
ADF	46.6	45.1	5.0	NS
Energy	72.9	77.5	2.6	*
DE,[4] MJ/kg of DM	13.4	14.0	0.4	*

[1]The forage fraction of diet 1 consisted of long fiber alfalfa hay; the forage fraction of diet 2 consisted of pelleted alfalfa.

[2]Residual standard deviation.

[3]$P > 0.05$.

[4]Digestible energy.

*$P \leq 0.05$.

***$P \leq 0.001$.

TABLE 3. Mean values for BW, N, and metabolizable energy (ME) according to type of diet.

Item[2]	Diet[1] 1	2	RSD[3]	P
BW, kg	49.7	49.1	9.7	NS
NI, g/kg$^{0.75}$ per d	2.242	1.659	0.35	*
NP, g/kg$^{0.75}$ per d	1.764	1.182	0.35	*
MEI, kJ/kg$^{0.75}$ per d	853	729	157	NS
MEP, kJ/kg$^{0.75}$ per d	452	328	157	NS
MN_o, g/kg$^{0.75}$ per d	0.36	0.36	0.13	NS
ME_o, kJ/kg$^{0.75}$ per d	264	290	100	NS
MN/NI	0.159	0.223	0.04	*
MN/NP	0.201	0.332	0.07	*
ME_o/MEI	0.304	0.401	0.06	*
ME_o/MEP	0.582	0.890	0.04	*

[1]The forage fraction of diet 1 consisted of long fiber alfalfa hay; the forage fraction of diet 2 consisted of pelleted alfalfa.

[2]NI = N Intake, NP = N available for production, MEI = ME intake, MEP = ME available for production, MN_o = milk N output, and ME_o = milk energy output.

[3]Residual standard deviation.

*$P \le 0.05$.

that available for production, for goats fed diet 1 was higher ($P \le 0.05$) than that for goats fed diet 2. This result was due to the higher CP content of diet 1 and the greater DMI of goats fed diet 1 compared with those fed diet 2. The amount of N secreted into the milk was the same for goats fed both diets. As a result, the ratio between milk N and N ingested or available for production was higher ($P \le 0.05$) for diet 2.

The intake of ME was estimated at 0.86 times the intake of digestible energy (1). Table 3 shows the ME intake and the ME available for production. The ME available for production was calculated by the difference between the ME ingested and that necessary for maintenance. The ME required for maintenance was estimated (1). All of these values are expressed as kilojoules per kilogram$^{0.75}$ per day. The energy content of milk (kilojoules per kilogram$^{0.75}$ per day) and the ratios between the energy content of milk and the ME ingested or available for production are presented (Table 3). Neither the intakes of ME nor the values of ME available for production were different between goats fed the two diets. Finally, the ratios between the energy in the milk and the ME ingested or available for production were higher ($P \le 0.05$) for goats consuming diet 2.

The differences detected in the efficiencies of N utilization or the ME ingested for milk production may be explained by considering the location at which fermentation was established. Given the physical form of diet 2, it is possible that there was a lower rate of ruminal protein degradation that could have led to a greater efficiency of N utilization for milk production, contributing at the same time to the greater efficiency of energy utilization (28). Various results from experiments with cows suggest that the proportion of digestible energy digested in the rumen decreases as the amount of bulky material in the diet decreases (28). This relationship would lead to a greater efficiency of energy utilization for milk production, which is what normally occurs (28). However, according to observations made for goats by Giger-Reverdin et al. (10), the time the feed spends in the rumen is closely related to the digestibility of the NDF, which in the present study was higher for diet 2 than for diet 1.

The greater efficiency of utilization of energy for milk production found for goats consuming diet 2 could have, at least in part, arisen from a mobilization of body reserves for milk production. The changes

TABLE 4. Milk production and milk composition for goats fed diets differing in the physical form of the forage fraction.

	Diet[1]			P	
	1	2	RSD[2]	Covariate	Diet
Milk production, g/d	1348	1306	327	*	NS
Milk composition					
DM, g/kg	149.3	161.2	8.1	*	NS
CP, g/kg	32.3	33.3	2.2	*	NS
Fat, g/kg	62.5	66.5	9.6	*	NS
Lactose, g/kg	49.7	53.4	5.4	NS	NS
Energy, MJ/kg	3.65	4.05	0.34	*	NS

[1]The forage fraction of diet 1 consisted of long fiber alfalfa hay; the forage fraction of diet 2 consisted of pelleted alfalfa.

[2]Residual standard deviation.

*$P \le 0.05$.

observed in BW of the goats were negative for both groups (–0.64 and –1.28 kg per goat during the total experimental period for diets 1 and 2, respectively). The values obtained, however, were by no means clearly indicative of a mobilization of reserves and could be explained by changes in the gut fill.

Composition of the Milk Produced

Determining factors. Table 4 shows values for milk production and composition. Except for lactose, mean values were affected ($P \leq 0.05$) by digestible energy intake, although no effect of diet could be detected.

In the ruminant, the pattern of ruminal fermentation that develops depends essentially on the amount and quality of the fiber fraction in the diet. The use of concentrates that are rich in readily fermentable carbohydrates, a decrease in the forage to concentrate ratio of the diet, and a decrease in the particle size of the fiber all tend to reduce the produced amount of acetic acid, which is the principal precursor of the fatty acids synthesized in the mammary gland. As a result, the fat content of the milk produced tends to be lower (28).

However, similar decreases are not always observed when goats are fed diets that are similar to those that were fed to cows and that led to a decrease in the milk fat content. Studies (12, 18) in which the forage to concentrate ratio of the diets of goats was varied greatly while the energy intake remained constant resulted in only small or insignificant changes in the fat content of the diet. Relative to those findings, Morand-Fehr et al. (16) reported that goats appeared to be less sensitive than cows to a deficiency in dietary fiber. Sauvant et al. (26) concluded that as long as the forage to concentrate ratio of the diet was greater than 20:80, the energy balance of the animal is more important in the determination of milk fat content than the relative proportion of these two constituents. Similarly Giger et al. (7), working with the same species, found that varying the nature of the dietary concentrates had no effect on the protein and fat contents in milk. Those researchers (7) concluded that, in goats, energy balance is the factor that is most significant in the determination of milk fat and protein contents. Morand-Fehr et al. (16) reported that, in goats, the physicochemical characteristics of the diet normally have only an indirect effect on the composition of the milk produced by modifying the energy intake that would normally take place.

The results obtained from the present study appear to agree completely with the observation of Morand-Fehr et al. (16); the composition of the milk produced depended essentially on energy intake. No differences in the milk fat and protein contents were observed as a result of the type of diet, despite the fact that, as mentioned previously, the utilization of N and energy intakes for milk production were higher for goats fed diet 2. For each diet, the values for ME intake (megajoules per day) and for milk production (grams per day) were positively correlated; the corresponding correlation coefficients were 0.75 for diet 1 and 0.92 for diet 2. In contrast, ME intakes were negatively correlated with milk protein and fat contents (grams per kilogram of milk); the corresponding correlation coefficients were –0.70 and –0.85 for diet 1 and –0.92 and –0.73 for diet 2, respectively.

When similar cases are examined, consideration should be given to the findings of Van Soest (29) who

TABLE 5. Milk protein fractions for goats fed diets differing in the physical form of the forage fraction.

	Diet[1]			
	1	2	RSD[2]	P
Whey protein, % of total protein	26.61	20.03	3.53	*
SA,[3] % of Whey protein	16.76	11.69	2.12	*
α-LA, % of Whey protein	27.24	28.04	4.19	NS
β-LG, % of Whey protein	56.01	60.28	5.10	NS
Casein, % of total protein	73.39	79.97	3.53	*
α_s-CN, % of Casein	34.88	25.95	6.04	*
β-CN, % of Casein	58.28	64.25	3.40	*
κ-CN, % of Casein	6.84	9.80	1.05	*

[1]The forage fraction of diet 1 consisted of long fiber alfalfa hay; the forage fraction of diet 2 consisted of pelleted alfalfa.

[2]Residual standard deviation.

[3]Seroalbumin.

*$P \leq 0.05$.

indicated that, given that ruminal turnover is related to $BW^{0.25}$ in small ruminants, the ruminal contents are replaced more rapidly by new contents. As a result, the animal has less time in which to retain and digest the constituents of the diet, including those that are digested more slowly. Consequently, small ruminants, that are similar to nonruminants obtain a lower proportion of their energy requirements from VFA; large quantities of nutrients leave the rumen to be digested directly in the abomasum and in the small intestine. Therefore, the energy balance of the animals is especially important in the determination of milk production and composition.

Protein fractions. Table 5 presents the mean values for the different protein fractions in milk produced by goats fed each diet. Diet affected ($P \leq 0.05$) milk protein fractions, except for α-LA and β-LG.

As Rook (24) observed, dietary characteristics that lead to a decrease in the fat content of bovine milk normally provoke an increase in the protein content and an increased amount of the more important protein fractions. In the experiments reported here, the milk protein from goats consuming diet 2 had a higher ($P \leq 0.05$) proportion of casein than did the milk protein from goats fed diet 1. This higher proportion of casein consisted of a lower percentage of α_s-CN and a higher percentage of β-CN and κ-CN. In contrast, the proportion of whey protein was lower in milk from goats fed this diet. Garciduenas (6) fed different types of forages to goats and found no differences in the yield of cheese made from caprine milk. Garciduenas (6) interpreted this result to indicate that no differences existed in the yield of coagulable protein formed. In the present study, a higher proportion of casein in the milk protein of goats fed diet 2, which supplied a somewhat higher amount of digestible fat, may be explained by the findings of Morand-Fehr et al. (16). Those researchers showed that fat supplements, even in small amounts, can lead to changes in the manufacturing properties of caprine milk, giving rise to a shorter coagulation time and the formation of a firmer gel. Both findings suggest the presence of a higher proportion of casein.

Fatty acid composition of the milk fat. Table 6 shows the fatty acid composition of the milk fat from goats fed each diet. Composition differed only minimally between goats fed the two diets. Only the concentration of butyric and linolenic acids were different between the two groups; the milk from goats fed diet 2 had lower ($P \leq 0.05$) percentages of these two acids than did the milk from goats fed diet 1.

When the milk fat content of ruminants declines because of alterations in the diet, the fatty acid composition of the milk fat also changes. The proportion of unsaturated fatty acids increases, and the proportion of saturated fatty acids decreases (24). Such changes were not observed in the present study. Saturated fatty acids constituted 71.1 and 70.3% of the milk fat from goats fed diets 1 and 2, respectively. This result further indicates the absence of the low milk fat syndrome (26). In addition to the importance of energy balance to determine the fat content of caprine milk, the results obtained here indicate that the dietary characteristics have no effect on the fatty acid composition of the milk fat. Giger et al. (7) found that, when goats were fed diets with different carbohydrates, the C_4 to C_{12}, C_{16}, and $C_{18:0}$ and $C_{18:1}$ concentrations in milk fat did not change. In the present study, the percentages of these three groups of fatty acids were 22.0 and 21.6%, 31.4 and 31.3%, and 35.9 and 36.6% for the milk fat from goats consuming diets 1 and 2, respectively. Finally, the proportion of fatty acids with 18 carbons or more arising from the diet and from the mobilization of body reserves, were almost identical for milk of goats fed diet 1 (38.2%) and diet 2 (38.8%). This result suggests that mobilization of body reserves was not affected by the type of diet consumed.

CONCLUSIONS

The milk composition and production of the Granadina goat appears to be more sensitive to energy intake than to the physical characteristics of the diet consumed. When the forage fraction of the diet was in the form of pelleted alfalfa instead of long alfalfa hay,

TABLE 6. Fatty acid composition (percentage) of milk fat for goats fed diets differing in the physical form of the forage fraction.

Fatty acid	Diet[1] 1	Diet[1] 2	RSD[2]	P
$C_{4:0}$	2.33	1.74	0.34	**
$C_{6:0}$	2.89	2.52	0.40	NS[3]
$C_{8:0}$	3.04	2.92	0.31	NS
$C_{10:0}$	9.69	10.18	1.05	NS
$C_{12:0}$	4.07	4.24	0.69	NS
$C_{14:0}$	9.39	9.66	0.63	NS
$C_{16:0}$	29.38	29.07	1.52	NS
$C_{16:1}$	0.97	0.83	0.92	NS
$C_{18:0}$	10.34	9.98	2.66	NS
$C_{18:1}$	25.55	26.65	7.22	NS
$C_{18:2}$	1.84	1.80	0.02	NS
$C_{18:3}$	0.34	0.25	0.04	**
$C_{20:4}$	0.17	0.13	0.03	NS

[1]The forage fraction of diet 1 consisted of long fiber alfalfa hay; the forage fraction of diet 2 consisted of pelleted alfalfa.

[2]Residual standard deviation.

[3]$P > 0.05$.

**$P \leq 0.01$.

the N and ME utilization for milk production were greater. According to these results, the use of pelleted alfalfa in the diets of goats would seem to be advantageous.

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