Feeding behaviour, digestibility, energy balance and productive performance of lactating goats fed forage-based and forage-free diets

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ABSTRACT

Six lactating Saanen goats have been used in a Latin Square design to evaluate a grass-based diet (G), a hay-based diet (H) and a nonforage diet (NF). On dry matter, grass and hay contributed for 55% of the diets and had 13.7 and 16.1% CP, 55.4 and 49.4% NDF, 38.0 and 31.6% ADF, respectively. Diet NF had beet pulp, cracked carob beans and whole cottonseed as main ingredients, with more than 75% of the particles greater than 2 mm.

Independently of the dietary treatment, the goats spent more time eating than ruminating. Diet NF proved to be effective in stimulating chewing activity, despite a trend for a lower chewing activity for eating (178, 185, 125 min/kg DMI for diets G, H and NF, respectively), but not for ruminating (84, 80, 80 min/kg DMI for diets G, H and NF, respectively). Feed intake did not differ among diets, while regarding digestibility diet NF had the highest values for DM (74.1%), OM (75.7%) and non-fibrous carbohydrates (92.0%), but the lowest for ADF (44.5%). For treatments G, H and NF milk yields were 3011, 3688 and 3212 g/d (P<0.05 between H and G), while milk fat and protein were respectively 3.37, 3.24, 2.96% (P<0.05 between G and NF) and 3.11, 3.32, 3.29%. Milk urea N was lower for diet NF (18.8, 18.6, 12.7 mg/100 ml, P<0.001). Diet NF increased the concentration of the short chain fatty acids of milk fat and decreased the content of C18:0, C18:1 and C18:3 in comparison to the other two diets. No difference among treatments was recorded for CLA. Intake energy was digested to a lesser extent for diet G (68.9, 70.0, 72.7%, P<0.05 between G and NF) due to its poor quality forage. Urinary energy losses reflected the corresponding protein contents of the diets, while no difference was recorded for methane production. ME resulted higher for diet NF (60.0, 60.7, 65.1% of the intake energy, P<0.01), while heat production and milk energy yield were similar in the three treatments. Diet NF had a higher ME content (11.13, 11.26, 11.93 MJ/kg DM, P<0.05), while no significant difference among the diets was recorded in terms of kl (0.64, 0.70, 0.69) and NE_l (7.20, 7.93, 8.30 MJ/kg DM).

It is concluded from the study that a nonforage diet with an adequate amount of structured fibre could substitute a ration based on poor quality forage in lactating goats; however, good forage seems to enhance milk performance to a greater extent.

Key Words: Goat, Nonforage diet, Chewing activity, Energy balance, Milk.

RIASSUNTO
COMPORTAMENTO ALIMENTARE, DIGERIBILITÀ, BILANCIO ENERGETICO E PERFORMANCE PRODUTTIVE DI CAPRE IN LATTAZIONE ALIMENTATE CON DIETE A BASE O PRIVE DI FORAGGI

Negli areali montani e collinari è difficile avere a disposizione foraggi di buona qualità che supportino le performance produttive degli animali in lattazione. Questa prova è stata approntata allo scopo di valutare, nella capra, l'utilizzo di una dieta priva di foraggi. Sei capre Saanen in lattazione sono state utilizzate in uno schema sperimentale a quadrato latino per valutare tre diete: una contenente erba (G), una fieno (H) e una priva di foraggi (NF). Erba e fieno costituivano il 55% della SS delle razioni e, sulla SS, avevano rispettivamente il 13,7 e il 16,1% di PG, il 55,4 e il 49,4% di NDF e il 38,0 e il 31,6% di ADF. La dieta NF conteneva: polpe di bietola, carrube frante e semi integrali di cotone e aveva oltre il 75% di particelle con diametro maggiore di 2 mm.

I risultati relativi all'attività masticatoria, indipendentemente dal trattamento, indicano che tutte le capre hanno trascorso più tempo nell'attività di ingestione dell'alimento rispetto alla ruminazione. La dieta NF ha portato le capre a ridurre l'attività masticatoria per l'ingestione (178, 185 e 125 min/kg SSI per le diete G, H e NF, rispettivamente) ma non per la ruminazione (84, 80 e 80 min/kg SSI per le diete G, H e NF, rispettivamente).

L'ingestione di SS non ha fatto registrare differenze significative tra le diete, mentre la digeribilità della dieta NF è risultata la più elevata per SS (74,1%), SO (75,7%) e NFC (92,0%), ma la peggiore per l'ADF (44,5%). Per le tre diete G, H e NF, la produzione di latte è stata rispettivamente di 3011, 3688 e 3212 g/d (P<0,05 tra H e G), la percentuale di grasso 3,37, 3,24 e 2,96 (con P<0,05 tra G e NF) e la percentuale di proteine 3,11, 3,32 e 3,29. Il minor contenuto di urea del latte è stato osservato per il trattamento NF: 12,7 mg/100 ml contro 18,8 e 18,6 mg/100 ml per G e H (P<0,001). Questo trattamento ha invece fatto aumentare la concentrazione degli acidi grassi a corta catena del grasso del latte, mentre ha ridotto il contenuto di $C_{18:0}$, $C_{18:1}$ e $C_{18:3}$ rispetto agli altri due trattamenti. La scarsa qualità dell'erba ha ridotto significativamente la digeribilità dell'energia ingerita (EI): 68,9% contro il 70,0 e il 72,7% delle diete H e NF (P<0,05 tra G e NF). L'energia metabolizzabile è risultata più elevata per la dieta NF (60,0, 60,7 e 65,1% dell'EI, P<0,01), mentre valori simili sono stati ottenuti per il calore prodotto e il contenuto energetico del latte. Il valore nutritivo delle tre diete non ha mostrato differenze significative sia quando espresso in termini di k_l (0,64, 0,70 e 0,69 per G, H e NF) che come energia netta latte (7,20, 7,93 e 8,30 MJ/kg SS).

I risultati ottenuti nella presente prova indicano che una razione totalmente priva di foraggi ma con un adeguato apporto di fibra strutturata potrebbe sostituire una razione basata su foraggi di scarsa qualità senza compromettere le performance produttive di capre da latte; lo stesso non si può affermare se il confronto è fatto con diete contenti fieni di elevata qualità.

Parole chiave: *Capre, Dieta priva di foraggi, Attività masticatoria, Bilancio energetico, Latte*

Introduction

In the climatic conditions of Italy, the milk performance of dairy goats is often penalized, both quantitatively and qualitatively, by the lack of good forage. Particularly, the quality of the forage (grass or hay) is sometimes so poor as to induce the farmer to integrate the diet with more concentrate. In some cases it is questionable if it would not be better, both from a nutritional and an economic point of view, to avoid low quality forage completely and rely only on a free forage diet. However, it must be proved that a nonforage diet does not hamper rumen activity and the health and performance of the animals. Previous research, performed as a simulation of an intensive productive system, indicates that goats tolerate a free forage diet for an entire lactation with milk performance similar to those of goats fed on a

silage based diet (Bava *et al.*, 2001). No evidence could be found in literature on a comparison between a nonforage diet and traditional diets based on grass or hay, in the lactating goat.

A free-forage diet has a great potential influence on the feeding behaviour of the animal and the ruminal fermentation pattern. In fact, chewing is the principal step in the process of forage tissue breakdown and the extraction of nutrients (Hadjigeorgiou *et al.*, 2003); chewing during eating and rumination is accompanied by an increase of saliva flow that ensures buffering capacity in the rumen; the reduction of feed particle size has a strong influence on accessibility of substrates to microorganisms in the rumen as well as density of particles which is related to the passage from the reticolorumen (Kaske *et al.*, 2002). The chewing activity is affected by particle size and fibre concentration of feed, dry matter intake, forage to con-

centrate ratio (Kawas *et al.*, 1991), species and size or age of animals (Hadjigeorgiou *et al.*, 2003; Mertens, 2000).

It is well known that in the ruminant the supply and the nature of fibre sources affect milk production and composition and sometimes cheese quality. Moreover, dietary fibre, as well as the composition of dietary lipids, can modify the content and the fatty acid composition of milk fat, even if goats seem to be more sensitive to the lipid content and composition of the diet than to the physical form or percentage of roughages in diet (Morand-Fehr *et al.*, 2000; Bava *et al.*, 2001). It is particularly well documented that grazing, especially in the case of high hill pastures, increases short chain fatty acids and PUFA of n-3 series and CLA, while it decreases medium and long chain of saturated fatty acids of meat and milk (Antongiovanni *et al.*, 2003).

Considering the efficiency of energy utilisation, previous studies indicated that lactating goats have generally high efficiency of utilization of metabolizable energy for lactation (k_l) (Aguilera *et al.*, 1990; Bava *et al.*, 2001). In the lactating cow the k_l values normally obtained in the calorimetric experiments are lower than those reported for goats (among others: Misciattelli *et al.*, 2001); however, some researchers found k_l values in the range of 0.65 (Nonaka *et al.*, 2001).

The aim of the present research was to investigate the feeding behaviour, the digestibility, the energy utilisation and the productive performance of lactating goats fed on a nonforage diet or two traditional forage-based diets.

Material and methods

Animals and diets

Six second-parity Saanen goats (55 ± 9 kg LW, on average) in mid lactation (106 ± 10 DIM, at the beginning of the trial) with similar 150-d milk yield in the previous lactation, were assigned to one of two squares in a duplicated 3 x 3 Latin square design. The experiment was conducted between the beginning of February and the secon half of April. The goats were allocated to individual metabolic cages to determine the apparent digestibility. Each digestibility trial lasted 21 days (13 days of adaptation followed by 8 days of collection).

The three treatments consisted of the following diets: grass and concentrate (diet G), hay and concentrate (diet H), no forage (diet NF). The first two diets had a forage to concentrate ratio equal to 55:45 on dry matter basis.

Grass was harvested from native pasture (1700 m on sea level altitude) located in Pra Maslino (Valtellina, Lombardy region, Italy) during summer; it was frozen (-20°C) and fed after being defrosted daily. The chemical analysis of the grass (24.4% DM), expressed on DM basis, was: 6.4% ash, 13.7% CP, 1.7% EE, 55.4% NDF, 38.0% ADF, 5.1% ADL, 22.8% non-fibrous carbohydrates (NFC=100-(ASH + CP + EE + NDF)).

Hay, a sun cured forage obtained from a permanent pasture of the same area, had the following analysis (on DM): 8.2% ash, 16.1% CP, 2.7% EE, 49.4% NDF, 31.6% ADF, 3.8% ADL, 23.6% NFC.

The nonforage diet was formulated to have protein and fibre content similar to those of the other two diets. Particularly, raw materials such as beet pulp, cracked carob beans, whole cottonseed, and whole maize grain were included in the diet NF with the aim to improve the chewing activity using the physically effective NDF system (Mertens, 1997).

The composition and analysis of the three administered diets are reported in table 1.

During the collection period, the goats were confined, for 4 days, in a respiration chamber to measure three 24-h cycles of respiratory exchange. Heat production was thus computed indirectly, with the open circuit respiration chamber system described by Crovetto (1984), using the equation proposed by Brouwer (1965).

Chewing recorder

A new apparatus was developed to record the chewing activity of the goats (Rapetti *et al.*, 2002a). The system is based on a principle analogous, as far as the sensor is concerned, to that described by Abijaoudè *et al.* (1999). It consists of a flexible silicone pipe 10 cm long, which is placed under the jaw of the animal. This pipe, fixed between the halter and the muzzle, is harmless to

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

		Diets		
		G	H	NF
Composition:				
Grass	% DM	55.3		
Hay	"		55.2	
Beet pulp	"			26.5
Cracked carob beans	"			25.8
Whole cotton seed	"			11.3
Soybean meal, 44%	"	10.3	10.3	12.0
Maize grain	"			9.6
Maize meal	"	29.0	29.1	9.8
Maize gluten meal	"	2.1	2.1	2.0
Limestone	"	0.90	0.90	0.72
Sodium bicarbonate	"	0.59	0.59	0.56
Dicalcium phosphate	"	0.68	0.68	0.76
Sodium chloride	"	0.45	0.45	0.45
Magnesium oxide	"	0.32	0.32	0.25
Vit.-min. supplement	"	0.26	0.26	0.26
Chemical analysis:				
DM	%	54.1	89.2	90.0
Ash	% DM	7.6	8.6	5.6
OM	"	92.3	91.4	94.4
CP	"	17.5	18.7	16.6
Ether extract	"	1.8	2.3	2.9
NDF	"	34.2	31.5	30.2
ADF	"	22.5	19.4	21.6
ADL	"	2.8	2.1	5.4
NFC	"	38.8	38.7	44.7
peNDF[1]	"	31.1	27.7	24.8

[1]peNDF = NDF (% on DM) x DM retained on 1 mm sieve.

the animal. At every jaw movement the compression of the pipe generates air pulses, which are transmitted, through a second smaller and less flexible tube, to a pressure sensor. This sensor transforms the air pulses into an electric signal, which in turn is sent to a small (126 x 57 x 26 mm) portable data logger weighing 120 g and containing a 9 volt battery. The data logger has a record capacity of 31924 observations, with the possibility to skip the periods with no chewing activity. This system permits measurement, with an interval of one second, of up to 32 jaw movements per observation. Based on the chewing frequency (chews/sec and cyclic pattern of the chewing activity) the chewing activity was attributed to the different aims: eating, ruminating, and accessory activity.

The device is connected to a computer with

specific software to register and save the data.

The 24 h chewing activity was recorded continuously by the automatic system for each period of the experiment. The different types of chewing activity (eating, ruminating, accessory activity) have been considered separately by means of the frequency of the jaw movements.

The total chewing activity was determined by recording the action of three goats (one for each treatment) continuously for 24 h during each of the three digestibility periods.

Experimental procedures and laboratory analyses

The animals were fed ad libitum twice daily at 08.30 and 17.30, allowing for about 20% orts. Before feeding, orts were collected and weighed. Samples of grass, hay, concentrate, NF diet, and orts were collected daily for the determination of DM content in a forced ventilation oven at 55°C until constant weight. Pooled samples of each item, for each collection period and animal, were used for analysis.

Faeces and urine were collected daily and sub-sampled as described by Rapetti *et al.* (2002b).

The goats were mechanically milked twice daily, at 07.30 and 18.30. Immediately after milking, the individual milk was weighed and a sample of 10% was placed in a bottle with about 20 mg of potassium dichromate as a preservative and stored at +4°C.

The raw materials of diet NF and of the concentrates of diets G and H were wet sieved by means of a vertical oscillating sieve shaker (Analysette 3 Spartan, Fritsch Gmbh) composed of 5 sieves (DIN/ISO 3310 serie) with mesh diameter of 8, 4, 2, 1 and 0.5 mm. A water flow of 2 L/min was applied on 50 g sample, with an oscillating range of 2 mm for 7 min. After sieving, the content of every sieve was dried at 105°C to determine the DM. The physically effective NDF (peNDF) was calculated following the method proposed by Mertens (1997) considering the DM retained on a 1 mm sieve instead of a 1.18 mm sieve. The peNDF of the forages was calculated assuming a DM retention on the sieve of 98%.

The analyses of feeds, orts and faeces were performed in accordance with the recommendations of the Italian Scientific Association for Animal Production (ASPA, 1980) for OM, ash, N and ether extract. The NDF, ADF and ADL were determined according to procedure of Van Soest *et al.* (1991).

Milk N was determined by the Kjeldahl procedure and fat content by the Gerber method in accordance with the recommendations of the Italian Scientific Association for Animal Production (ASPA, 1995). Milk samples were also analysed for lactose (Milkoscan 605, Foss, Hillerød, Denmark), SCC (Fossomatic 360, Hillerød, Denmark) expressed as a linear score $(LS = \log_2 (SCC/12,500))$, and milk urea N (CL; Eurochem, Italy). Fatty acid composition of milk fat was determined by means of gas chromatography of methyl ester derivatives obtained by sodium methoxide according to ISO (1996). The following gas chromatographic conditions were used: apparatus, Gas Chromatograph Perkin-Elmer 8410 equipped with a flame ionisation detector; column, FFAP 0.53x15 m (1 µ film); carrier, helium at 3.5 psi; temperature program, 65 °C (3 min) then to 235 °C at 10 °C/min.

The gross energy of all samples (diets, orts, faeces, urine and milk) 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 (Rapetti *et al.*, 2002b).

Milk yield energy was also corrected in function of retained energy as follows: milk yield energy (MYE_c) = milk yield energy + (1.05 positive retained energy) or (MYE_c) = milk yield energy + (0.84 negative retained energy) (ARC, 1980).

The efficiency of use of the metabolisable energy for lactation (k_l) was calculated with the following equation: $k_l = MYE_c / (MEI - ME_m)$ where MEI is the metabolisable energy intake and ME_m is the metabolisable energy for maintenance. The ME_m was determined by means of regression analysis between milk yield energy plus retained energy versus MEI for each treatment.

Net energy for lactation (NE_l) was computed as: ME x k_l; the milk fodder units (UFL) were calculated as: $NE_l / 7.1128$.

Statistical analysis
Data were analysed by ANOVA using a gener-

al linear model (SAS, 2000). As the Latin square design was applied, each goat received the three different diets, resulting in n=6 observations per treatment. The following model was utilised:

$$Y_{ijk(t)} = \mu + S_i + A_{ij} + P_k + T_{(t)} + e_{ijk}$$

where: $Y_{ijk(t)}$ = dependent variable; μ = general mean; S_i = square effect (i=1,2); A_{ij} = animal effect within square (j=1,3); P_k = period effect (k=1,3); $T_{(t)}$ = diet effect (t=1, 3); e_{ijk} = residual error.

For the statistical analysis of the chewing activity the same model was applied without the square effect (n=3 observations per treatment).

Results and discussion

Chewing behaviour

The diet NF had more than 75% of the particles greater than 2 mm, while more than 90% of the concentrate particles were smaller than 1 mm. The biggest particles of the diet NF belonged to carob beans, whole cottonseed, maize grain and, to a lesser extent, to beet pulp (figure 1).

Table 2 reports the data referred to the chewing activity of the animals fed on the three diets.

No significant difference was noticed between treatments probably due to the individual variation caused by the fact that only three animals have been utilized for this aim.

The data indicate that, independently of the dietary treatment and of the way the chewing activity is expressed (min/d, min/kg DMI, min/kg NDF ingested), the goats spent more time eating than ruminating. This is consistent with the results obtained by Abijaoundé *et al.* (2000) and confirms that goats are more efficient "chewers" than cattle and sheep, as reported by Hadjigeorgiou *et al.* (2003). No significant difference was found between treatments despite a lower value for diet NF in terms of total chewing activity. Interestingly, diet NF determined the same chewing activity for rumination as the other two diets; hence, the difference between diet NF and the forage based-diets in terms of total chewing activity is attributable exclusively to the chewing activity for eating, which was expected because of the different length of the feed particles.

Table 2.   Chewing behaviour in dairy goats fed the three diets.

		Diets			SEM	Probability[1]		
		G	H	NF		G vs H	G vs NF	H vs NF
ET	min/d	372	517	276	105	ns	ns	ns
RT	"	172	229	173	21	ns	ns	ns
CT	"	544	746	449	108	ns	ns	ns
AT	"	148	164	140	43	ns	ns	ns
ETU	min/kg DMI	178	185	125	36	ns	ns	ns
RTU	"	84	80	80	15	ns	ns	ns
CTU	"	263	265	205	45	ns	ns	ns
ETNDF	min/kg NDF	512	601	415	129	ns	ns	ns
RTNDF	"	244	263	261	51	ns	ns	ns
CTNDF	"	756	864	677	155	ns	ns	ns

*ET: eating time per day; RT: ruminating time per day; CT: chewing time per day; AT: accessory activity per day.*
ETU: eating time per unit of ingested feed; RTU: ruminating time per unit of ingested feed; CTU: chewing time per unit of ingested feed (CTU=ETU+RTU).
ETNDF: eating time per g of ingested NDF; RTU: ruminating time per g of ingested NDF; CTU: chewing time per g of ingested NDF.
[1]*ns: not significant.*

Figure 1. Particle distribution of raw materials of diet NF.
The figure reports only the quantities greater than 15% for each sieve.
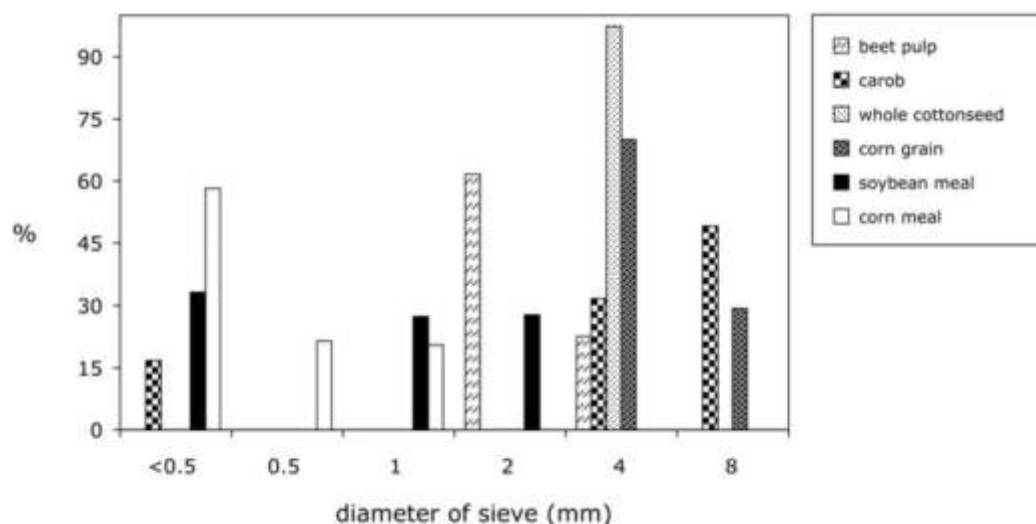
Feed intake and digestibility

Table 3 shows the data obtained for the three diets. DM intake was not significantly different among treatments when expressed either as g per day or as g per metabolic weight. Bava *et al.* (2001) in a previous work registered a higher feed intake with a nonforage diet in comparison with a control (forage based) diet, but it must be underlined that the feed composition of that nonforage diet was strongly different from the NF ration of the pre-

Table 3. Daily dry matter intake and apparent digestibility (Least Square Means) of the three diets.

		Diets			SEM	Probability[1]		
		G	H	NF		G vs H	G vs NF	H vs NF
Intake:								
DMI	g	2054	2354	2101	159.7	ns	ns	ns
DMI	g/kg$^{0.75}$	104	116	107	7.41	ns	ns	ns
App. Digestibility:								
DM	%	69.7	70.5	74.1	0.91	ns	**	*
OM	"	71.4	73.1	75.7	0.96	ns	*	0.1
N	"	69.2	72.1	64.0	1.66	ns	0.1	**
Ether extract	"	72.0	78.2	82.6	3.43	ns	0.1	ns
NDF	"	52.1	61.1	55.2	2.14	*	ns	0.1
ADF	"	50.4	55.5	44.5	1.38	*	*	***
NFC	"	87.5	83.6	92.0	0.63	**	***	***

[1] * P < 0.05; **P < 0.01; ***P < 0.001; ns: not significant.

Table 4.   Milk yield and composition (Least Square Means).

		Diets			SEM	Probability[1]		
		G	H	NF		G vs H	G vs NF	H vs NF
Milk yield	g/d	3011	3688	3212	182.1	*	ns	0.1
4% FCM	"	2723	3243	2739	143.9	*	ns	*
Fat	"	101	118	97	5.23	**	ns	*
Protein	"	93	121	104	4.45	**	ns	*
Fat	%	3.37	3.24	2.96	0.09	ns	*	0.1
Protein	"	3.11	3.32	3.29	0.09	ns	ns	ns
Lactose	"	4.33	4.38	4.44	0.04	ns	*	ns
NPN	% total N	10.0	9.7	8.6	0.64	ns	ns	ns
Casein N	"	68.4	70.7	73.7	1.88	ns	*	ns
Urea N	mg/100 ml	18.8	18.6	12.7	0.82	ns	***	***
LS[2]		8.19	7.02	7.36	0.46	ns	ns	ns

[1] * $P < 0.05$; **$P < 0.01$; ***$P < 0.001$; ns not significant.
[2] LS = linear score = $\log_2 (SCC/12500)$.

sent experiment and characterized by a high lignin content and consequently by a low digestibility.

Differences among treatments, despite the great absolute values registered (e.g. DMI of diet G was lower of 15% than diet H), cannot be at all ascribed to the dietary treatments, because of the very high variability registered among animals: in fact, in the present trial, the SEM of DMI (table 3) resulted up to eight-fold the value registered in other experiments (Rapetti *et al.*, 1997; Rapetti *et al.*, 2002b). As a matter of fact, there was not a clear trend of the influence of the dietary treatments on feed intake.

Digestibility of DM and OM was significantly higher for the diet NF in comparison with the other two diets, particularly diet G. The latter resulted as having a significantly lower digestibility of NDF and ADF as compared to diet H. This is presumably due to the quality of the grass which was worse than the hay, as already reported. The diet NF had a lower ADF digestibility (44.5%) as compared to diet G (50.4%, P<0.05) and to diet H (55.5%, P<0.001). Since diet NF also had the lowest protein digestibility, its high OM digestibility has to be ascribed mainly to the NFC fraction; in

this respect, it has to be underlined that the contribution of maize to the NFC of diet NF is lower (19.4%) than that of the other two diets (29%). Therefore, the NFC fraction of feeds like carob beans and beet pulp is likely to be highly digestible.

Milk yield and composition

Table 4 summarizes the main milk performance of the animals in the experiment. Diet H gave the highest daily milk yield (3.7 kg) followed by diet NF (3.2 kg) and diet G (3.0 kg, P<0.05). It is difficult to explain why diet H had the highest milk yield; we can speculate on the possible reasons but without the support of experimental evidence. Diet NF had a high NFC content (44.7% on DM) but a large proportion of it is represented by soluble fibre (pectins) which is fermented mainly to acetate (Broderick *et al.*, 2003), with a consequent lower feed efficiency (Armstrong and Blaxter, 1965) and higher heat expenditure, as numerically confirmed by the value of heat production reported in table 6. On the other hand, diet H had a higher starch content (21.9% on DM) and this should lead to a higher glucose supply and a consequent lower heat expenditure. The

Table 5. Effect of the experimental diets on the composition % fatty acids content in milk (Least Square Means).

		Diets			SEM	Probability[1]		
		G	H	NF		G vs H	G vs NF	H vs NF
Fatty acids (wt %)								
Butyric	C_4	2.90	2.95	2.79	0.392	ns	ns	*
Caproic	C_6	2.61	2.65	2.78	0.036	ns	*	*
Caprylic	C_8	2.73	2.81	3.16	0.062	ns	**	**
Capric	C_{10}	8.84	9.35	11.44	0.235	ns	***	***
Lauric	C_{12}	3.93	4.41	5.75	0.225	ns	***	**
Myristic	$C_{14:0}$	10.18	11.00	11.71	0.333	ns	*	ns
Myristoleic	$C_{14:1}$	0.16	0.18	0.23	0.020	ns	*	ns
Palmitic	$C_{16:0}$	24.19	24.42	27.94	0.536	ns	**	***
Palmitoleic	$C_{16:1}$	1.30	1.25	1.51	0.061	ns	*	*
Stearic	$C_{18:0}$	10.18	9.36	5.23	0.557	ns	***	***
Oleic	$C_{18:1}$	23.07	21.70	17.18	0.605	ns	***	***
Linoleic	$C_{18:2}$	3.70	3.36	4.11	0.168	ns	ns	*
Linolenic	$C_{18:3}$	0.47	0.68	0.14	0.023	***	***	***
Con. Linol.	$C_{18:2conj}$	0.81	0.78	1.13	0.160	ns	ns	ns

[1] * $P < 0.05$; **$P < 0.01$; ***$P < 0.001$; ns: not significant.

higher milk yield of diet H can be attributed to the higher feed and energy intake associated to this diet and to the better conversion of metabolisable energy into milk.

Unfortunately the broad variation among animals and the low number of degrees of freedom did not evidentiate significance for most of the differences registered.

The low milk fat content of treatment NF (2.96%) might be attributed to the higher adipogenesis of animals fed the NF diet (confirmed by a higher RE) which adressed more digested long chain fatty acids to tissues rather than to the udder. The low milk fat content of diet NF determined a significant difference in terms of 4% fat corrected milk (FCM) for this diet as compared to diet H (2.7 vs 3.2 kg/d, P<0.05). The milk protein content was similar for the three diets and higher, in diets H and NF, than the fat content. This might be due to the higher net energy content of these two diets (table 6) in comparison to diet G.

The casein N was higher with diet NF than

with diet G, while NPN was lower. This can be attributed, as stated previously, to the higher NE content of diet NF in comparison to diet G. A higher milk protein and casein content of dietary treatments higher in energy is confirmed by other authors (Sanz Sampelayo et al., 1998). On the contrary, it is evident that the significantly lower urea concentration of diet NF in comparison with the other two diets was due to the lower protein and the higher NFC content of this diet. Moreover, the low nitrogen digestibility of diet NF (Table 3) determined a lower content of digested N and this was utilised more efficiently in comparison with the other two diets, as it will be discussed in the paragraph on N balance.

Looking at the fatty acid composition of the milk fat (table 5) it is clear that diet NF increased the concentration of the short chain (C_6-C_{12}), the C_{16} and the $C_{18:2}$, but decreased the content of the $C_{18:0}$, $C_{18:1}$ and $C_{18:3}$ fatty acids in comparison to the other two diets.

The data obtained are consistent, on average,

Table 6. Energy intake, partition and concentration of the experimental diets (Least Square Means).

		Diets			SEM	Probability[1]		
		G	H	NF		G vs H	G vs NF	H vs NF
Gross Energy intake (EI)	MJ/d	38.1	43.5	38.6	3.02	ns	ns	ns
Energy partition:								
Faecal energy[2]	% EI	31.1	30.0	27.3	0.99	ns	*	ns
Digestible energy[2]	"	68.9	70.0	72.7	0.99	ns	*	ns
Urinary energy[3]	"	3.24	4.17	1.91	0.20	*	**	***
Methane energy[3]	"	5.68	5.18	5.76	0.32	ns	ns	ns
Metabol. energy (ME)[3]	"	60.0	60.7	65.0	0.81	ns	**	**
Heat production[3]	"	35.3	31.7	35.5	2.19	ns	ns	ns
Milk energy[2]	"	22.0	23.2	22.1	0.84	ns	ns	ns
Retained energy[3]	"	2.74	5.74	7.43	2.78	ns	ns	ns
Corr. milk energy (MYE$_C$)[3]	"	25.3	29.4	30.0	2.10	ns	ns	ns
Energy partition:								
Heat production[3]	% ME	59.0	52.3	54.6	3.50	ns	ns	ns
Milk energy[2]	"	36.6	38.3	34.1	1.42	ns	ns	ns
Retained energy[3]	"	4.36	9.36	11.35	4.58	ns	ns	ns
Corr. milk energy (MYE$_C$)[3]	"	41.9	48.4	46.2	3.38	ns	ns	ns
Diet energy concentration:								
Gross energy	MJ/kg DM	18.5	18.6	18.3	0.06	ns	*	*
Digestible energy	"	12.8	13.0	13.33	0.20	ns	ns	ns
ME[3]	"	11.1	11.3	11.9	0.17	ns	*	*
k_l[4]		0.64	0.70	0.69	0.03	ns	ns	ns
NE$_l$[5]	MJ/kg DM	7.20	7.93	8.30	0.36	ns	ns	ns
UFL	/kg DM	1.01	1.11	1.17	0.05	ns	ns	ns

[1] * $P < 0.05$; **$P < 0.01$; ***$P < 0.001$; ns: not significant
[2] Data computed individually (n = 6)
[3] Data computed in pairs (n = 3)
[4] k_l = corrected milk energy (MYE$_c$) / (MEI – ME$_m$), where MYE$_c$ and MEI are expressed as kJ/kg $^{0.75}$ and ME$_m$ = 403 kJ/kg$^{0.75}$
[5] NE$_l$ = ME * k_l
[6] UFL = NE$_l$ / 7.1128

with those obtained by other authors (Sanz Sampelayo *et al.*, 2002) and the differences between diet NF and the forage based-diets seem due to the different fatty acid profile of the three diets. For example, the high palmitic and linoleic content of the whole cotton seed determined a higher content of these fatty acids in the fat milk of the goats fed on diet NF.

Diet G gave linoleic and conjugated linoleic acid (CLA) concentrations lower or similar to those of diet NF. This is not consistent with the data obtained in several studies (among others, Antongiovanni *et al.*, 2003) where animals grazing on fresh pasture produced a milk with a higher content of CLA. However, it must be underlined, as reported by Chilliard *et al.* (2002), that the CLA content of the grass is strongly influenced by several factors such as the stage of maturity, the

Table 7.   Nitrogen balance of the experimental diets (Least Square Means).

		Diets			SEM	Probability[1]		
		G	H	NF		G vs H	G vs NF	H vs NF
Nitrogen partition:								
N intake (NI)	g/Kg$^{0.75}$	2.96	3.44	2.79	0.165	ns	ns	*
N faecal losses	"	0.91	0.97	1.01	0.089	ns	ns	ns
N urine losses	"	0.83	1.01	0.49	0.044	*	***	***
N milk losses	"	0.70	0.95	0.84	0.052	**	ns	ns
N retention	"	0.47	0.47	0.40	0.080	ns	ns	ns
Nitrogen partition:								
N intake (NI)		100	100	100				
N faecal losses	% NI	30.8	27.9	36.0	1.66	ns	ns	**
N urine losses	"	27.9	29.4	18.5	1.42	ns	**	***
N milk losses	"	23.5	27.7	29.8	1.62	ns	*	ns
N retention	"	16.1	13.6	13.8	2.38	ns	ns	ns

[1] * $P < 0.05$; **$P < 0.01$; ***$P < 0.001$; ns: not significant

botanical composition and the seasonal changes in availability.

Finally, the lower concentration of linolenic acid in diet NF can be due to the lower maize content of this diet.

Energy partition

Energy intake and digestibility (table 6) of the three treatments are consistent with the results dealing with DM intake and digestibility already discussed. Particularly, diet G registered a low energy digestibility due to the poor quality of the forage. Urinary energy losses reflect the corresponding protein contents of the three diets, with diet NF having the lowest protein intake and the lowest urinary energy output.

Methane energy losses were similar for the three diets. This result can be explained by the fact that diet NF, although with a lower NDF content, had a considerable amount of pectins which, similarly to hemicellulose and cellulose, are fermented to volatile fatty acids and primarily to acetic acid (Van Soest, 1994) which promotes methanogenesis (Russell, 1998).

ME content was significantly higher (P<0.01) in diet NF. Heat production and milk yield energy were similar in the three treatments and comparable to those obtained in previous experiments (Bava *et al.*, 2001; Rapetti *et al.*, 2002b). The data obtained show a trend for higher energy retention with diets H and NF, but the differences among diets are not statistically significant.

The regression between milk yield energy plus retained energy versus MEI obtained from treatment G resulted not significant while those determined for the other two treatments were not different at the parallelism test. Hence, a unique regression was performed on the data of treatments H and NF (figure 2). ME_m resulted to be 403 kJ/kg$^{0.75}$, in agreement with the observation (401 kJ/kg$^{0.75}$) of Aguilera *et al.* (1991). The energy concentration of the experimental diets indicate a higher ME content for diet NF, while no significant difference among the diets was revealed in terms of k_l and NE_l, despite a trend for higher values for the diets H and NF. The high NE_l and UFL values of the three diets are consistent with those obtained by our research group in previous trials (Bava *et al.*, 2001; Rapetti *et al.*, 2002b) and suggest that lactating goats can utilise dietary and metabolisable energy very efficiently.

Figure 2. Relationship between the metabolisable energy intake and the net energy for production (milk yield energy and retained energy).
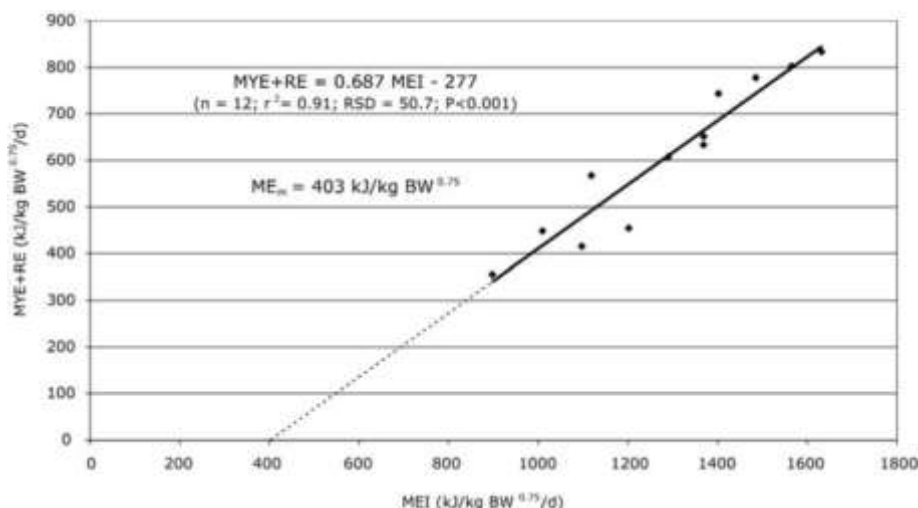
Nitrogen balance

From Table 7 it is evident that diet NF induced, expressed as a proportion of the intake nitrogen, a higher faecal and a lower urinary nitrogen excretion. The latter is consistent with the lower urea nitrogen content of milk produced by goats fed the NF diet, as previously discussed. The higher faecal nitrogen output of NF diet should be ascribed to the lower protein digestibility of this diet (Table 3) which in turn is due to the low protein digestibility of some feed ingredients such as beet pulp (Andrieu *et al.*, 1988).

Conclusions

The data obtained in this experiment indicate that a nonforage diet formulated to supply a sufficient amount of structured fibre in order to promote a normal chewing and rumen activity could substitute a ration based on poor quality forage in lactating goats. Good forage (hay in this experiment) enhances milk performance, but a low quality forage, even if highland fresh grass, could not be a guarantee for good quantitative and qualitative performance.

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