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ABSTRACT

The efficiency of utilisation of diets with different proportions of energy sources (starch, fat, lactose) was studied with three pairs of lactating Saanen goats; the animals were fed, in a Latin square design, 3 silage-based diets containing (on DM basis) the following energy sources: 32% maize meal (diet M); 4.7% rumen-protected fat (Megalac®) and 23.5% maize meal (diet F); 9.8% milk whey permeate powder and 22.3% maize meal (diet W). During each of the three experimental periods, 8 days of total collection balance trials were conducted during which goats were allocated for 72 h (three 24 h cycles) in open circuit respiration chambers to determine methane and heat production and, hence, the energy balance. Diet F, in comparison with diets M and W, significantly increased the milk fat content (4.13 vs 3.11 and 3.14%, P<0.001) and the 4%-FCM yield (3367 vs 2927 and 3055 g/d, P<0.01 and P<0.05, respectively), while no relevant changes were observed for milk protein content and yield. Energy digestibility was equal in diets F and W. Megalac® did not decrease fibre digestibility. The partition of the gross energy intake (EI) differed significantly between diets: diet M had lower DE (72.4 vs 74.3 and 74.3%; P<0.01) and ME (62.1 vs 64.7 and 63.5%; P<0.05) in comparison with diets F and W, respectively. Energy lost as methane was not significantly decreased by the inclusion of rumen-protected fat in the diet, although a trend for a reduction of methanogenesis was observed. Heat production determined by treatment F was lower in comparison with the other treatments. This difference was almost significant (P=0.056) when expressed as a percentage of the ME. Milk energy output increased significantly (+12%, P<0.001) by including fat in the diet, as compared with treatments M and W: 21.4 vs 19.1 and 19.0% of the EI. The net energy content of the protected fat was 27.94 MJ NE_l/kg DM (+340% vs maize meal); its k_l value resulted 0.77. The corresponding values for whey permeate were 7.76 MJ NE_l/kg DM (-5% vs maize meal) and 0.50, respectively. Summarizing, the efficiency of energy utilization in diet M was significantly lower in comparison with the other two diets in terms of digestibility and metabolisability, while its NE_l content was similar to that of diet W. On the other hand, diet F had a significantly higher ME (P<0.01) and NE_l (P<0.05) as compared to the other two diets. Diet F greatly influenced the fatty acid composition of the milk fat with less short (-30%) and medium (-33%) chain fatty acids and more (+18%) long chain fatty acids. In conclusion, whey permeate and even more Megalac® can be successfully used as feed ingredients in the diet of highly productive lactating goats, but the economical convenience of their utilisation must be evaluated based on the market values of feedstuffs.

Key words: Dairy goat, Energy metabolism, Rumen-protected fat, Whey permeate.

RIASSUNTO

INFLUENZA DI FONTI ENERGETICHE DIFFERENTI SULL'UTILIZZAZIONE ENERGETICA E LA COMPOSIZIONE ACIDICA DEL GRASSO DEL LATTE NELLA CAPRA

In un esperimento a quadrato latino effettuato su tre coppie di capre Saanen in lattazione, si è studiata l'efficienza di utilizzazione di tre diverse fonti energetiche: amido, grasso, zuccheri. Le tre diete avevano quale costituente base l'insilato di loiessa e, sulla SS, contenevano rispettivamente: a) il 32,0% di farina di mais (dieta M); b) il 4,7% di grassi rumino-protetti (Megalac®) e il 23,5% di farina di mais (dieta F); c) il 9,8% di permeato di siero di latte (a base di lattosio) e il 22,3% di farina di mais (dieta W).
Durante ognuno dei tre periodi sperimentali, per 8 giorni si è effettuata una raccolta individuale giornaliera degli escreta e, tramite impiego di camere respiratorie, la determinazione della produzione di metano e di calore per il calcolo del bilancio energetico associato ai tre trattamenti alimentari è stata realizzata in 72 h (3 cicli da 24 h).
Rispetto alle diete M e W, la dieta F ha aumentato significativamente (P<0,001) il tenore in grasso del latte (4,13 vs 3,11 e 3,14%) e la produzione di latte corretto al 4% di grasso (3367 vs 2927 e 3055 g/d, P<0,01 e P<0,05, rispettivamente), mentre non sono state registrate differenze significative in termini di tenore proteico e di produzione di proteine con il latte.
La digeribilità dell'energia è stata simile per le diete F e W. Il Megalac® non ha ridotto la digeribilità della fibra. La ripartizione dell'energia ingerita (EI) è stata significativamente diversa per le tre diete: la dieta M ha avuto una minore ED (72,4 vs 74,3 e 74,3%; P<0,01) ed EM (62,1 vs 64,7 e 63,5%; P<0,05) rispetto alle diete F e W, rispettivamente.
L'energia persa sotto forma di metano non è stata significativamente ridotta dall'inclusione nella dieta di grasso rumino-protetto, benchè si sia registrata una tendenziale minor metanogenesi. La produzione di calore associata al trattamento F è risultata minore rispetto agli altri trattamenti, con una differenza quasi significativa (P=0,056) allorchè espressa come percentuale dell'EM.
La produzione di energia sottoforma di latte è aumentata significativamente (+12%, P<0,001) con l'inclusione nella dieta di grasso rumino-protetto, rispetto ai trattamenti M e W: 21,4 vs 19,1 e 19,0% dell'EI.
Il contenuto in energia netta del grasso protetto, calcolato a partire dai valori di EN_l *della farina di mais e della farina di estrazione di soia tabulati dall'NRC (1989), è risultato pari a 27,94 MJ* EN_l*/kg SS (+340% vs la farina di mais); il suo valore di* k_l *è risultato pari a 0,77. I corrispondenti valori per il permeato di siero sono stati pari a 7,76 MJ* EN_l*/kg SS (-5% vs la farina di mais) e a 0,50, rispettivamente.*
Il trattamento F ha influenzato fortemente la composizione acidica del grasso del latte, con una minor presenza di acidi grassi a corta (-30%) e a media (-33%) catena e una maggior presenza di acidi grassi a lunga catena (+18%).
In conclusione, il permeato di siero ed ancor più il Megalac® possono essere impiegati con successo nell'alimentazione della capra a elevata produzione di latte, anche se la convenienza economica del loro impiego va valutata di volta in volta in funzione del valore di mercato dei diversi mangimi.

Parole chiave: *Capra da latte, Metabolismo energetico, Lipidi protetti, Permeato di siero.*

Introduction

Dietary energy is normally the main limiting factor in the production of high yielding lactating ruminants. Under intensive feeding conditions, a high proportion of the dietary energy is derived from cereal starch that is partially digested in the rumen (Huntington, 1997). Other energy sources can be utilised: carbohydrates completely degraded in the rumen, such as lactose, or feeds that are inert in the forestomach, such as rumen-protected fat.

Experiments with milk whey permeate (whey without most of its serum protein content) in dairy goats, as well as in other lactating ruminants, are not available in literature. The use of milk by-products as feed ingredients for lactating goats reported in literature are limited to liquid whey (Broqua and de Simiane, 1983; Hacala, 1989; Rapetti *et al.*, 1995).

Milk whey and its by-products are pollutants and their utilisation in diet formulation offers interesting prospects as respects their possible inclusion among feed supplements used to improve animal performance, especially in terms of increased milk fat (Schingoethe and Skyberg,

Table 1. Composition, chemical analysis and gross energy content of the offered diets.

		Diets		
		M	F	W
Composition (% of DM)				
Italian ryegrass silage		49.7	52.4	49.7
Maize meal		32.0	23.5	22.3
Soybean meal 44% CP		15.9	16.8	15.9
Whey permeate powder		-	-	9.8
Rumen-protected fat(1)		-	4.7	-
Limestone		1.37	1.48	1.31
Mono-dicalcium phosphate		0.46	0.50	0.44
Sodium chloride		0.46	0.50	0.44
Vit.-min. supplement		0.11	0.12	0.11
Chemical analysis				
Dry matter	%	42.2	41.1	42.4
Organic matter	% DM	89.9	89.2	89.4
Crude protein	"	17.1	17.2	18.0
UIP(2)	% CP	34.9	33.8	32.4
Ether extract	% DM	3.9	6.7	3.7
NSC(3)	"	38.8	36.0	38.1
NDF	"	34.0	36.0	33.3
ADF	"	18.5	19.9	18.5
Gross energy	MJ/kg DM	17.91	18.83	17.98

(1) *calcium soaps of long chain fatty acids (Megalac®).*
(2) *UIP: undegradable intake protein, calculated from NRC (1989) tables.*
(3) *NSC: Non structural carbohydrates, calculated as: NSC = OM-(CP+EE+NDF).*

1981; Crovetto *et al.*, 1990; Rapetti *et al.*, 1995), which is linked to the increased butyrate yield in the rumen (Windschitl and Schingoethe, 1984).

Rumen-protected fats as feed ingredients for lactating ruminants have been widely tested in many experiments. The main effects recorded are higher milk yield (Schneider *et al.*, 1988; Andrew *et al.*, 1991; Garcia-Bojalil *et al.*, 1998), improved milk fat content (Baldi *et al.*, 1992; Lu, 1993; Teh *et al.*, 1994; Rousselot *et al.*, 1995; Brown-Crowder *et al.*, 1997) and modified fatty acid composition of the milk fat (Baldi *et al.*, 1992; Palmquist *et al.*, 1993; Beaulieu and Palmquist, 1995; Rotunno *et al.*, 1998). Additional effects, such as lower dry matter intake (DMI) (Grummer *et al.*, 1990; Schauff and Clark, 1992) and decreased milk protein content (Lanzani *et al.*, 1985; Bartocci *et al.*, 1988; Sutton, 1988) are sometimes reported. However, very few experiments have attempted to determine the efficiency of energy utilisation and consequently the net energy for lactation (NE_l) content of rumen-inert fats (Van der Honing, 1979; Andrew *et al.*, 1991).

The aim of this research was to investigate the efficiency of utilisation and NE_l content of three different dietary energy sources (maize, rumen-protected fat and whey permeate) in lactating goats and their influence on milk yield and composition.

Material and methods

Six multiparous Saanen goats (third lactation, 52±5.8 kg BW) in mid-lactation (106±16 days in milk) were paired and fed ad libitum three diets, in a Latin square design, where each pair of goats received each dietary treatment in three consecutive periods. The forage to concentrate ratio was about 1:1 on a dry matter basis.

The three diets (table 1) were formulated using different concentrate energy sources (maize meal, rumen-protected fat and whey permeate), as follows: approximately 9-10 percentage units of the DM of maize meal were substituted with the equivalent Gross Energy (GE) content of calcium soaps of palm fatty acids (Megalac®, Volac Limited, UK; fatty acid content: 84%; approximate fatty acid profile: $C_{14:0}$=1.5%, $C_{16:0}$=44.0%, $C_{18:0}$=5.0%, $C_{18:1}$=40.0% and $C_{18:2}$=9.5%) or whey permeate powder (Volac Limited, UK; 81.9% lactose, 7.8% CP, 1.1% EE, and 9.2% ash, on a DM basis). The dietary treatments were: M, the control diet with 32.0% maize meal; F, 4.7% calcium soaps of palm fatty acids and 23.5% maize meal; W, 9.8% whey permeate powder (based on lactose) and 22.3% maize meal (table 1).

The forage utilised in the trial was an Italian ryegrass (*Lolium multiflorum* Lam.) silage harvested at the beginning of the heading stage, wilted for one day in the field and then chopped at a length of 4-5 cm before ensiling. The silage had the following chemical composition: 27.5% DM and, on a dry matter basis, 88.4% OM, 12.3% CP, 58.7% NDF, 35.0% ADF, 18.49 MJ GE/kg, 4.6% lactic acid, 1.12% acetic acid, and 0.25% propionic acid; the pH was 3.9.

The chemical analyses of the diets are reported in table 1. These analyses were computed from the analysis of the forage and the analysis of each concentrate mixture for each dietary treatment.

The goats were allocated to individual metabolic cages to determine the individual apparent digestibility. The digestibility trials consisted of 15 days of adaptation followed by 8 days of collection.

The animals were fed twice daily at 08.30 and 17.30. Before feeding, orts were collected and weighed. Samples of the silage, of each of the three concentrate mixture and orts were collected daily for the determination of DM content in a forced ventilation oven at 60°C for 72 hours. Pooled samples of each item, for each collection period and animal, were used for analysis.

Faeces and urine were collected daily and subsampled: 20% of the total weight for faeces and 10% of the total weight for urine. Two samples of urine were obtained and a preservative added: for nitrogen and energy determinations, the urine was acidified with 10% - on a weight basis - of a solution containing 10% H_2SO_4 by volume; for the determination of the chemically bound CO_2 (required to calculate total CO_2 production), formalin (10 ml/l urine) was added to the urine sample.

The goats were mechanically milked twice daily, at 07.30 and 18.30 hours. 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 -20°C.

The analyses of the silage, the three concentrate mixtures, orts, faeces, and urine were performed in accordance with the recommendations of the Italian Scientific Association for Animal Production (ASPA, 1980). Samples of silages were analysed for organic acids and ammonia N in order to correct the DM content according to Dulphy and Demarquilly (1981). The gross energy of all the samples was determined in an adiabatic calorimeter (IKA® C 4000, Staufen, Germany); liquid samples (urine and milk) were placed in polyethylene bags (5x7 cm, weighing about 200 mg), freeze dried and then burnt in the calorimeter (Nijkamp, 1969, 1971).

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). The fatty acid composition of milk 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 μfilm); carrier, helium at 3.5 psi; temperature program, 65°C (3 min) then to 235°C at 10°C/min.

Measurements of the respiratory exchanges were recorded utilising two open-circuit respiration chambers described by Crovetto (1984). During the collection period, each of the three pairs of goats was confined in the respiration chamber for 72 hours (three 24 h-cycles). Total heat production (HP) was determined by indirect calorimetry from the respiration exchanges using the equation of Brouwer (1965): 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.

Milk yield energy (YE) was also computed as corrected milk yield energy (YE_C) in function of the retained energy (RE) in the body as follows: YE_C = YE+1.014 RE (when RE>0) (Rapetti *et al.,* 1997).

The efficiency of use of metabolisable energy (ME) for lactation (k_l) was calculated with the following equation: $k_l=YE_C/[ME-ME_m]$, assuming the ME for maintenance (ME_m) value of 484 kJ/kg $BW^{0.75}$ (Rapetti *et al.*, 1997). Both the coefficient (1.014) utilised to calculate YE_C and the value of 484 kJ ME_m/kg $BW^{0.75}$ were previously determined by means of regression analysis utilising an energy balance data set performed on Saanen goats in mid lactation which included the goats of this trial. Net energy of lactation (NE_l) was then computed as: ME * k_l.

The energy concentration of the forage was calculated as the difference in energy concentration of diet M from the energy concentration of maize and soybean meal tabulated by NRC (1989) without considering associative effects. The same computation was performed for the Megalac® and whey permeate in diets F and W, respectively, assuming the average energy content of the forage calculated previously.

Data were analysed by ANOVA using a general linear model (SAS, 1994). Because of the Latin square design applied, each goat received the three different diets, resulting in n = 6 observations per treatment. The following model was utilised:

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

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

For the variables referred to the respiratory trials (methane, HP, ME, YE_C, NE_l, RE) the experimental units were represented by the pairs of goats, resulting in n=3 observation per treatment. Therefore, the following model was applied for these variables:

$$Y_{ij(t)} = m + C_i + P_j + T_{(t)} + e_{ij}$$

where: $Y_{ij(t)}$ = dependent variable; m = general mean; C_i = pair of animals effect (i=1,2,3); P_j = period effect (j=1,2,3); $T_{(t)}$ = diet effect (t=1,2,3); e_{ij} = residual error.

Comparisons among treatment means were performed according to the Scheffé test.

Results and discussion

Feed consumption

The small quantities of feed refusals and the limited selection by the goats determined a negligible difference between the diets offered and those actually ingested.

Average daily DM intake (table 2) for treatment W was significantly higher in comparison

Table 2. Effect of the experimental diets on dry matter intake, milk yield and composition.

		Diets			SEM
		M	F	W	
DMI	g/d	2453^{b}	2400^{bB}	2593^{aA}	29
Milk yield	"	3369	3273	3489	62
4% FCM	"	2927^{bB}	3367^{aA}	3055^{b}	61
Milk fat	%	3.11^{BB}	4.13^{AA}	3.14^{BB}	0.05
Milk fat	g/d	105^{BB}	140^{AA}	111^{BB}	2.5
Milk protein	%	2.93	3.03	2.98	0.03
Milk protein	g/d	97	99	102	1.5

Values within a row followed by different letter differ significantly (lower-case letter: P<0.05; capital letter: P<0.01; double capital letter: P<0.001) according to Scheffé's test (n=6 for each treatment).

with M and F (2593 vs 2453, P<0.05, and vs 2400 g, P<0.01). While no data are available in literature about the influence of whey permeate on feed intake by dairy goats, rumen-protected fats, in agreement with our results, did not significantly change feed intake by lactating goats in comparison with a control diet (Teh *et al.*, 1994). The high DMI attained with diet W might be attributable to the high palatability of the whey permeate.

Milk production

Milk yields (table 2) were not statistically influenced by the treatment diets. The milk fat concentration increased considerably with diet F in comparison to M and W diets (4.13 vs 3.11 and 3.14%, P<0.001), while milk protein content was not affected by the different energy sources. The positive effect of rumen-protected fat on milk fat content confirms the results obtained in previous studies (Baldi *et al.*, 1992; Lu, 1993; Teh *et al.*, 1994; Rousselot *et al.*, 1995; Brown-Crowder *et al.*, 1997).

The strong increase in milk fat content recorded for diet F determined a significant improvement in the 4% fat-corrected milk (FCM) yield (g/d) with diet F (3367) in comparison to treatments M (2927, P<0.01) and W (3055, P<0.05).

Digestibility

Diet W had a significantly higher OM digestibility (table 3) than diet M (P<0.01) probably because of the higher digestibility of lactose in comparison with maize starch. However, there was no significant difference in energy digestibility between diets W and F, due to the higher contribution of fat to digestible energy in diet F.

Moreover, as expected, fibre digestibility was not depressed by the inclusion of a considerable amount of rumen-inert fat in the diet.

Diet M had the lowest digestibility coefficients for most of the parameters considered, despite the reasonably good absolute values.

Energy partition

Table 4 reports the partition of energy intake (EI) and ME for the three diets. Diet M had the lowest (P<0.01) digestible energy (DE).

Energy lost as methane did not significantly decrease with the inclusion of rumen-protected fat in the diet. This agrees with the lack of a depression of fibre digestibility registered in diet F, but is not consistent with the results of a previous study on lactating cows (Andrew *et al.*, 1991), although a trend toward a reduction in methanogenesis with treatment F was observed.

Urinary energy losses were slightly, but signif-

Table 3. Apparent digestibility of dietary components of the ingested diets.

		Diets			SEM
		M	F	W	
DM	%	70.6^{B}	70.9^{B}	72.6^{A}	0.26
Ash	"	39.0^{A}	33.8^{B}	40.4^{A}	0.84
OM	"	74.2^{B}	75.3^{AB}	76.4^{A}	0.30
N	"	63.5^{b}	71.1^{a}	69.2^{ab}	1.54
EE	"	82.9	77.5	80.8	1.78
NSC	"	93.0^{B}	95.3^{AB}	97.3^{A}	0.58
NDF	"	57.6	59.5	57.1	0.75
ADF	"	57.5	59.7	58.1	0.97
Energy	"	72.4^{B}	74.3^{A}	74.3^{A}	0.30

Values within a row followed by different letter differ significantly (lower-case letter: P<0.05; capital letter: P<0.01) according to Scheffé's test (n=6 for each treatment).

icantly, reduced by treatment W (P<0.05), but we cannot give a satisfactory explanation for this.

Metabolisability (ME/EI) of diet M (62.1%) was lower (P<0.05) than that of the other two diets (64.7% and 63.5% for F and W, respectively); this has to be ascribed mainly to the reduction in energy digestibility already discussed.

Heat production determined by treatment F resulted lower in comparison with the other treatments, particularly when expressed as a percentage of the ME. This difference was almost significant (P=0.056) and was consistent with the typically low heat increment of fat and with the results of Andrew *et al.* (1991).

Milk energy output was significantly increased (+12%) by the addition of fat to the diet in comparison with treatments M and W (21.4 vs 19.1 and 19.0% of EI; P<0.01) while no difference between treatments was recorded in terms of retained tissue energy, in agreement with Palmquist and Conrad (1978) and Andrew *et al.* (1991).

Milk energy yield, expressed as a percentage of ME, indicated a trend toward better energy utilisation with diet F in comparison with treatments M and W.

Energy content of the diets and feed ingredients

Table 4 summarises the energy values of the three diets. Diet F had significantly higher gross, digestible, metabolisable and net energy concentrations in comparison with the other two diets. Comparing diets M and W, the latter had a higher (P<0.05) DE, but similar ME and NE_l content; therefore, the two treatments were

Table 4. Energy intake, partition and concentration of the experimental diets.

		Diets			SEM
		M	F	W	
Energy intake (EI) $^{(1)}$	MJ/d	44.60	45.41	46.68	0.53
Energy partition					
Faecal energy$^{(1)}$	% EI	27.6^{A}	25.7^{B}	25.8^{B}	0.30
Digestible energy$^{(1)}$	"	72.4^{B}	74.3^{A}	74.3^{A}	0.30
Methane gas energy$^{(2)}$	"	7.5	6.8	8.2	0.18
Urinary energy$^{(1)}$	"	2.8^{a}	2.8^{a}	2.5^{b}	0.07
Metabolisable energy (ME)$^{(2)}$	"	62.1^{b}	64.7^{a}	63.5^{a}	0.10
Heat production$^{(2)}$	"	36.0	35.7	36.8	0.20
Milk energy$^{(1)}$	"	19.1^{B}	21.4^{A}	19.0^{B}	0.30
Tissue energy$^{(2)}$	"	7.0	7.6	7.7	0.44
Heat production$^{(2)}$	% ME	58.0	55.2	57.9	0.47
Milk energy$^{(1)}$	"	30.7	33.1	29.9	0.59
Tissue energy$^{(2)}$	"	11.3	11.7	12.2	0.69
Energy concentration					
Gross energy$^{(1)}$	MJ/kg DM	18.18^{B}	18.93^{A}	18.00^{B}	0.02
Digestible energy$^{(1)}$	"	13.17^{cB}	14.06^{aA}	13.37^{bB}	0.05
Metabolisable energy$^{(2)}$	"	11.29^{B}	12.25^{A}	11.43^{B}	0.02
$k_l^{(2)}$		0.636	0.662	0.624	0.012
$NE_l^{(2)}$	"	7.18^{b}	8.11^{a}	7.14^{b}	0.15

Values within a row followed by different letter differ significantly (lower-case letter: P<0.05; capital letter: P<0.01) according to Scheffé's test.

$^{(1)}$ Data computed from each animal (n=6 per treatment).

$^{(2)}$ Data computed from each pair of animals (n=3 per treatment).

practically equivalent. Considering the k_l, no significant difference could be found despite a clear trend in favour of the diet containing rumen-protected fat.

The calculated energy values of Megalac® and whey permeate are reported in table 5. The ME (36.29 MJ/kg DM), NE_l (27.94 MJ/kg DM) and k_l (0.77) values calculated for Megalac® utilising the NRC tabulated data (NRC, 1989) for maize and soybean meal, are in good agreement with the data obtained with lactating cows by Andrew et al. (1991): 35.31 MJ ME/kg DM, 27.28 MJ NE_l/kg DM and a k_l of 0.77.

Whey permeate had a higher ME (+11% on average) but a lower NE_l content (-5% on average) in comparison with maize; as a consequence, the k_l of whey permeate was lower than that of maize: 0.50 vs 0.59, on average. The low efficiency in the utilisation of the ME from whey permeate in comparison with the ME from maize can probably be explained by the lower energetic efficiency of acetic and butyric acids (whose yield in the rumen is enhanced by the lactose of whey) as compared to propionic acid, whose yield is enhanced by maize starch.

The NE_l content of the Italian ryegrass silage derived from the NE_l values of maize and soybean meal tabulated from NRC (1989) was 6.53 MJ NE_l/kg DM. This value is consistent with that (6.33 MJ NE_l/kg DM) obtained in a previous experiment on wethers (Crovetto *et al.*, 1996).

Milk fat composition

Table 6 reports the composition of the milk fat in terms of fatty acids, and cholesterol. In comparison with diet M, diet W did not significantly change the milk fat composition; on the contrary, the inclusion of rumen-protected fat in the diet caused a significant change in the fatty acid profile of the milk fat. In particular, a decrease in the short (C_6-C_{10} decreased on average of 30%; P<0.001) and the medium (C_{12}-$C_{14:1}$ decreased on average of 33%; P<0.001) chain fatty acids was recorded, together with an increase (+18%; P<0.001) in the long chain fatty acids (C_{16}-$C_{18:1}$), in agreement with the fatty acid composition of the rumen-protected fat utilised. The passage of the long chain fatty acids contained in the rumen-protected fat into milk is well documented (Grummer, 1991; Jenkins, 1993; Palmquist *et al.*, 1993; Ashes *et al.*, 1997). The decrease in the short chain fatty acids recorded in the milk produced by treatment F could reduce the presence of free C_6-C_{10}, with a possible reduction in the typical flavour of goat milk (Skjevdal, 1979).

Significantly lower milk cholesterol was also recorded for diet F in comparison with diet M: 0.38 vs 0.75 (P<0.05). This is not consistent with the results obtained in other experiments where the influence of calcium soaps of fatty acids on plasma cholesterol was investigated (Marty and Block, 1990; Espinoza *et al.*, 1998).

Table 5. Estimated energy values of Italian ryegrass silage, protected fat and whey permeate powder.

		Maize[1]	SBM[1]	It. ryegrass silage[2]		Protected fat[3]		Whey permeate[4]	
				Mean	SD	Mean	SD	Mean	SD
ME	MJ/kg DM	13.97	13.77	9.14	0.35	36.29	1.22	15.58	1.38
NE_l	"	8.20	8.12	6.53	0.98	27.94	1.14	7.76	2.51
k_l (NE_l/ME)		0.59	0.59	0.71	0.08	0.77	0.04	0.50	0.17

(1) *Energy values tabulated by NRC (1989)*
(2) *Data computed from treatment M (n=3)*
(3) *Data computed from treatment F (n=3)*
(4) *Data computed from treatment W (n=3)*

Table 6. Effect of the experimental diets on the composition of fatty acids and cholesterol content of milk.

		Diets			SEM
		M	F	W	
Fatty acids (wt %)					
Butyric	C_4	2.0	2.3	2.2	0.06
Caproic	C_6	2.2	2.0	2.3	0.07
Caprylic	C_8	2.8[A]	2.1[BBB]	2.9[AA]	"
Capric	C_{10}	11.7[AA]	7.6[BB]	12.1[AA]	0.22
Lauric	C_{12}	5.4[AA]	3.1[BB]	5.5[AA]	0.16
Myristic	$C_{14:0}$	12.6[AA]	8.9[BB]	12.6[AA]	0.14
Myristoleic	$C_{14:1}$	0.4[AA]	0.2[BBB]	0.3[A]	0.02
Palmitic	$C_{16:0}$	34.4[B]	38.5[aA]	35.3[b]	0.56
Palmitoleic	$C_{16:1}$	1.5	1.8	1.4	0.05
Stearic	$C_{18:0}$	6.6[b]	7.4[aAA]	5.8[BB]	0.11
Oleic	$C_{18:1}$	17.2[BB]	23.0[AA]	16.5[BB]	0.20
Linoleic	$C_{18:2}$	2.7	2.7	2.5	0.15
Linolenic	$C_{18:3}$	0.6	0.6	0.6	0.11
Cholesterol (wt %)		0.8[a]	0.4[b]	0.7[ab]	0.08

Values within a row followed by different letter differ significantly (lower-case letter: P<0.05; capital letter: P<0.01; double capital letter: P<0.001) according to Scheffé's test (n=6 for each treatment).

Conclusions

In comparison with the control diet based on maize meal, the diet containing whey permeate determined a significantly higher DM intake and a slightly higher energy digestibility, but similar NE_l content.

The estimated nutritive values of the energy sources tested in the trial, show greater efficiency in the energy utilisation of rumen-protected fat in comparison with starch or lactose. In particular, the net energy content (NE_l) of Megalac® and whey permeate are 340 and 95% of maize meal, respectively.

The inclusion in the diet of approximately 5% rumen-protected fat (calcium soaps of long chain fatty acids) determined an increase in milk fat content with a modification of its fatty acid profile (decrease in the short and medium and increase in the long chain fatty acids). FCM yield was increased by rumen-protected fat without a reduction of milk protein.

Furthermore, the comparison of the results of this experiment with the data contained literature shows a great similarity in energy utilization of rumen-inert fat between lactating goats and cows.

In conclusion, both Megalac® and whey permeate can be successfully used as feed ingredients in the diet of highly productive lactating goats, but the economical convenience of their utilisation must be evaluated based on the market values of feedstuffs.

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