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Effects of palm oil and calcium soaps of palm oil fatty acids in fattening diets on digestibility, performance and chemical body composition of lambs

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Abstract

The effects on digestibility, performance and chemical body composition of inclusion of palm oil (PO, VETALGRAS®) or calcium soaps of palm oil fatty acids (CaF, MAGNAPAC®), at two levels, in diets of growing lambs were determined. Experimental diets consisted of barley straw and one of five concentrate supplements: control (C, no fat added), low level of PO (LPO, 25 g PO/kg), low level of CaF (LCaF, 31 g CaF/kg), high level of PO (HPO, 41 g PO/kg) and high level of CaF (HCaF, 50 g CaF/kg). Concentrations of supplemental fatty acids in the diets were 25 and 41 g/kg for the two supplementation levels. Concentrates with added fat were formulated to be isonitrogenous

Abbreviations: ADF, acid detergent fibre; ADG, average daily gain; C, control diet; CaF, calcium soaps of palm oil fatty acids; CP, crude protein; DM, dry matter; DMI, DM intake; EE, ether extract; FA, fatty acids; FCR, feed conversion ratio; HCaF, high level of calcium soaps of palm oil fatty acids diet; HPO, high level of palm oil diet; LCaF, low level of calcium soaps of palm oil fatty acids diet; LPO, low level of palm oil diet; LW, live weight; NDF, neutral detergent fibre; OM, organic matter; PDI, protein truly digestible in the small intestine; PO, palm oil; POFA, palm oil fatty acid; SW, slaughter weight

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and isoenergetic and the five supplements had the same energy:protein ratio. The experiment was completed with 30 male Ojalada lambs (6 lambs per treatment) from weaning (initial live weight 14.1 ± 0.5 kg) until 25 kg live weight. Inclusion of fat decreased digestibility of acid detergent fibre (0.525 *versus* 0.438, P<0.05) and increased ether extract digestibility (0.645 *versus* 0.770, P<0.05). Ether extract (EE) digestibility increased (LPO and LCaF *versus* HPO and HCaF, P<0.05) when the level of added fat increased (0.727 *versus* 0.814). There was a significant effect of interaction (P<0.05) between the level and type of fat on the organic matter (OM) and neutral detergent fibre (NDF) digestibility of the diets. Diets HPO presented lower digestibility values (LPO *versus* HPO, P<0.05) than LPO with regard to OM (0.844 *versus* 0.819) and NDF (0.503 *versus* 0.435). Nevertheless, this effect was not observed when fat was added in the form of calcium soaps (LCaF *versus* HCaF, P>0.05). At the low level of fat inclusion, OM digestibility was greater when fat was in the form of PO than when it was as CaF (0.844 in LPO *versus* 0.823 in LCaF, P<0.05). At the high level of fat inclusion, NDF digestibility was greater when fat was included in the form of CaF rather than PO (0.435 in LPO *versus* 0.500 in HCaF, P<0.05). Average daily gain (ADG) and days to 25 kg were not affected by the treatments. The feed conversion ratio (FCR, g DMI/g daily gain) was lower (C *versus* LPO, LCaF, HPO and HCaF, P<0.05) when fat was added to the diets than control animals (3.21 *versus* 2.86). The treatments studied produced no differences in carcass yield. Statistically significant differences in chemical composition and energy content of carcass and non-carcass components were not observed. Inclusion of up to 41 g of fat from palm oil or calcium soaps of palm oil fatty acids per kilogram of the concentrate of growing lambs improves EE digestibility and the feed conversion ratio without affecting carcass yield and body chemical composition. Inclusion of palm oil fatty acids as calcium soaps avoided the negative effects on fibre digestibility observed when 41 g PO/kg were added to the diet.

Keywords: Lambs; Palm oil; Calcium soaps; Digestibility; Animal performance; Body composition

1. Introduction

In most Mediterranean countries, lambs are either slaughtered between 10 and 12 kg live weight (LW), thereby reducing their productive phase to the suckling stage, or grown with concentrates under intensive husbandry conditions and slaughtered between 20 and 30 kg. Lambs need a high energy ration to assure high productivity and fast growth. Chilliard (1993), Chilliard and Ollier (1994), Clinquart et al. (1995) and Doreau and Chilliard (1997) have noted that inclusion of fats in the diet may be appropriate for ruminants with high energy requirements. In addition, fats prevent ruminal acidosis, facilitate absorption of liposoluble nutrients and make it possible to modify meat or milk fat composition according to consumer demand. Moreover, supplementing feeds with fat improves granule quality and reduces dust formation (Perez et al., 2002). All these advantages, together with increasing market availability of fats and oils at competitive prices, entice feed manufacturers to include fats in concentrates.

Nevertheless, fats included in ruminant diets may negatively alter voluntary intake and fibre digestibility. Dietary fat may modify the ruminal microbial population, which is responsible for cellulose digestion, but has few effects on other propionate-producing organisms

(Clinquart et al., 1995; Doreau and Chilliard, 1997; Sauvant and Bas, 2001). Inclusion of fat in ruminant diets improves energy efficiency due to the lower ruminal production of methane and direct use of long-chain fatty acids in the metabolic pathways of fat synthesis, without the need for acetate and glucose (Clinquart et al., 1995; Doreau and Chilliard, 1997; Machmüller et al., 2000).

Studies conducted to assess effects of fats on nutrient digestibility, performance and body composition of ruminants have not yielded consistent results. This could be due to a variety of factors, such as the level and/or source of dietary fat and the nature of the basal diet, which determine effects of fat on ruminal microbes (Doreau and Chilliard, 1997).

Until a few years ago, most fats used in ruminant diets were of animal origin. However, the negative reaction in Europe to use of animal-origin supplements in ruminant diets has increased interest in their substitution by vegetable oils (Perez et al., 2002). Palm oil is one of the principal vegetable fats available on the market at competitive prices and can also be purchased in the form of oil or calcium soaps. As they are “dry fats”, calcium soaps facilitate fat inclusion in the diet and may also avoid some of the negative effects of dietary fats on ruminal fermentation (Grummer, 1988; Nigdi et al., 1990; Jenkins, 1993).

There have been several studies on effects of different fats of vegetable origin in diets of beef cattle (Zinn, 1989; Clinquart et al., 1995; Beaulieu et al., 2002; Duckett et al., 2002) and fattening lambs (Preziuso et al., 1999; Russo et al., 1999; Bas and Morand-Fehr, 2000; Machmüller et al., 2000; Kott et al., 2003; Ivan et al., 2004). Less work has been done on the use of palm oil (Solomon et al., 1992; Lough et al., 1993) or calcium soaps of palm oil fatty acids in growing lambs (Moibi and Christopherson, 2001; Demirel et al., 2004). None of these studies contrasted specific effects of inclusion of palm oil or calcium soaps of palm oil fatty acids on productivity, digestibility and body composition of growing lambs.

The aim of this work was to study effects of rations that included different levels of palm oil or calcium soaps of palm oil fatty acids on digestibility, performance and body composition of growing weaned lambs raised under intensive management conditions and slaughtered at about 25 kg.

2. Materials and methods

2.1. Animals and diets

Thirty Ojalada weaned male lambs [initial live weight, 14.1 ± 0.5 kg] of 45 days of age were randomly assigned to one of five dietary treatments and housed in individual pens with sawdust bedding. The five experimental diets consisted of barley straw as the forage and one of five concentrate supplements. All concentrates contained barley grain, corn grain, wheat grain and soybean meal, but varied according to their content in palm oil (PO, VETALGRAS®, NOREL SA, Madrid, Spain) or calcium soaps of palm oil fatty acids (CaF, MAGNAPAC®, NOREL SA, Madrid, Spain). Two levels of PO and CaF in the experimental concentrates were studied being the low level (L) of 25 g fatty acids/kg

Table 1
Ingredients of the concentrate (g/kg)

Ingredient	Concentrate[a]				
	C	LPO	LCaF	HPO	HCaF
Barley grain, ground	101	200	305	100	230
Corn grain, ground	423	281	200	336	247
Wheat grain, ground	250	177	150	81	41
Wheat bran	–	50	50	130	120
Soybean meal (expeller, 440 g CP/kg)	192	230	228	259	255
Palm oil[b]	–	25	–	41	–
CaF[c]	–	–	31	–	50
Calcium carbonate	14	17	16	25	25
Dicalcium phosphate	–	–	–	1.2	4.4
Sodium bicarbonate	10	10	10	10	10
Sodium chloride	3.0	3.0	3.0	1.0	1.0
Aroma[d]	1.0	1.0	1.0	1.0	1.0
Antioxidant[e]	0.2	0.2	0.2	0.2	0.2
Vitamin mineral premix[f]	6.0	6.0	6.0	6.0	6.0

[a] C, control without fat added; LPO, low level of palm oil; LCaF, low level of calcium soaps of palm oil fatty acids; HPO, high level of palm oil; HCaF, high level of calcium soaps of palm oil fatty acids.

[b] Palm oil (VETALGRAS®, NOREL SA, Madrid, Spain). Analysis: 995 g fat/kg. Fatty acid composition (NOREL SA, g/kg total fatty acids): C16:0, 500–550; C18:0, 30–60; C18:1, 300–350; C18:2, 80–100.

[c] CaF: calcium soaps of palm oil fatty acids (MAGNAPAC®, NOREL SA, Madrid, Spain). Analysis: 950 g/kg of DM, 815 g/kg of total fatty acids and 135 g/kg of total ash (90 g/kg calcium). Fatty acid composition (NOREL SA, g/kg fatty acids): C14:0, 15; C16:0, 440; C18:0, 50; C18:1, 400; C18:2, 95.

[d] Aroma (APENZIMA 6, NOREL SA, Madrid, Spain).

[e] Antioxidant (OXAN, NOVATION, SA, Arcos de Jalón, Soria, Spain).

[f] Vitamin mineral premix (NUTEMIX®, NUTEGA, Madrid, Spain). Contained (per kg) 1,000,00 IU Vitamin A; 200,000 IU Vitamin B3; 10,000 IU Vitamin E; 300 mg Vitamin B1; 200 mg Vitamin B2; 2.75 mg Vitamin B12; 50 mg Se; 133 g Mg.

and the high level (H) of 41 g fatty acids/kg. As the fatty acid content of CaF is lower than that of PO (815 g/kg *versus* 995 g/kg, respectively), a higher proportion of CaF than of PO was used. The five experimental diets (Table 1) and their respective treatment groups were denominated as control (C, no added fat), low level of PO (LPO, 25 g PO/kg), low level of CaF (LCaF, 31 g CaF/kg), high level of PO (HPO, 41 g PO/kg) and high level of CaF (HCaF, 50 g CaF/kg). Concentrates with added fat (PO or CaF) were formulated to be isonitrogenous and isoenergetic, and the five experimental concentrates had the same energy:protein ratio in terms of metabolizable energy (ME) and protein truly digestible in the small intestine (PDI). ME and PDI values of the feedstuffs (Table 2) were calculated using the ME and PDI values of the individual dietary ingredients (FEDNA, 1999).

Weaned lambs were gradually adapted to the experimental diets over 10 days. Barley straw and each of the five concentrate supplements were offered separately, *ad libitum*, once daily (09:00 h) and uneaten feed was removed daily at 08:30 h throughout the experimental period of 40.2 ± 2.91 days in order to determine dry matter (DM) intake and the feed conversion ratio (FCR). Clean drinking water was available in plastic buckets for all lambs. Lambs were weighed at the beginning and end of the study and twice a week dur-

Table 2
Chemical composition (g/kg DM), metabolizable energy value (ME, MJ/kg DM), protein value (PDI) and mineral composition of the experimental diets

	Barley straw	Concentrate[a]				
		C	LPO	LCaF	HPO	HCaF
Dry matter	920	963	964	962	963	964
Crude protein	33	186	190	191	199	198
Ether extract	16	30.3	53.4	45.8	65.6	60.6
Ash	66	56	64	76	72	100
NDF	807	117	138	138	139	159
ADF	457	37	46	44	44	49
ME	5.5	12.5	12.7	12.7	12.7	12.7
PDI		128	130	130	130	130
PDI (g):ME (MJ)[b]	–	10.2	10.2	10.2	10.2	10.2
Ca[b]	3.3	85	91	111	124	140
P[b]	0.8	41	45	45	52	57
Mg[b]	1.1	1.9	2.0	2.1	2.0	2.4

[a] Concentrates: C, control without fat added; LPO, low level of palm oil; LCaF, low level of calcium soaps of palm oil fatty acids; HPO, high level of palm oil; HCaF, high level of calcium soaps of palm oil fatty acids.
[b] ME: metabolizable energy; PDI: protein truly digestible in the small intestine; Ca, P and Mg estimated using FEDNA (1999).

ing the experimental period. In the third week of the experimental period, four randomly selected lambs from each treatment (19.2 ± 0.57 kg LW) were fitted with harnesses for faecal collection and adapted to the harnesses over a 2-day period. Faeces were collected for 5 days and subsequently analysed to measure apparent digestibility (Table 3). Digestibility measurements and handling did not cause statistically significant differences in animal performance.

Table 3
Apparent digestibility coefficients of the diets

	Treatments[a]					S.E.M.	Significance of contrast			
	C	LPO	LCaF	HPO	HCaF		Control *vs.* fat	Level of fat[b]	Type of fat[c]	Level × type of fat
Dry matter	0.824	0.816	0.795	0.782	0.801	0.0218	0.08	0.21	0.89	0.09
Organic matter	0.844	0.844ac	0.823b	0.819d	0.836	0.0129	0.12	0.39	0.77	0.01
Crude protein	0.775	0.789	0.763	0.775	0.813	0.0311	0.63	0.26	0.71	0.06
NDF	0.503	0.503c	0.474	0.435ad	0.500b	0.0376	0.32	0.28	0.36	0.03
ADF	0.525	0.482	0.426	0.386	0.459	0.0619	0.04	0.32	0.78	0.06
Ether extract	0.645	0.777	0.676	0.796	0.831	0.0707	0.01	0.03	0.38	0.08

Means within fat level with different letters (a and b) differ (P<0.05). Means within type of fat with different letters (c and d) differ (P<0.05).
[a] Treatment: C, control without fat added; LPO, low level of palm oil; LCaF, low level of calcium soaps of palm oil fatty acids; HPO, high level of palm oil; HCaF, high level of calcium soaps of palm oil fatty acids.
[b] LPO and LCaF *vs.* HPO and HCaF.
[c] LPO and HPO *vs.* LCaF and HCaF.

This study was conducted following the guidelines of Spain's University of Valladolid regarding the principles and ethical considerations that must be taken into account when using animals for research.

2.2. Slaughter and sampling

Lambs were slaughtered at 25 kg LW. During the 12 h previous to slaughter, lambs had access to water but not to feed. All lambs were shorn prior to slaughter and their fleece was weighed. The mass of bleedable blood was recorded after slaughter and the gastrointestinal tract was emptied and its contents weighed. Skin, feet, head, internal organs and empty gastro intestinal tract constituted the non-carcass component. The commercial carcass, with kidneys and perinephral fat, was weighed while still warm and then kept at a temperature of 4 °C for 24 h. Cold carcass weight was recorded before the carcass was split into two halves. The right half constituted the carcass component.

The right half-carcass and the non-carcass components were cut into small pieces, minced separately in a meat grinder and subsampled for chemical composition and gross energy content.

2.3. Chemical analyses

Samples of feeds, refusals and faeces were oven-dried at 60 °C to constant weight and procedures described by the AOAC (1995) were used to determine ash (AOAC official method 942.05), crude protein (CP, AOAC official method 984.13) and ether extract (EE, AOAC official method 920.39). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) determinations were completed according to methods of Van Soest et al. (1991), using the ANKOM$^{200/220}$ Fibre Analyser (ANKOM Technology Corp., Fairport, NY, USA). NDF analysis was performed without sodium sulphite, with alpha amylase and expressed with residual ash. ADF was also expressed with residual ash.

Samples of the right half-carcass and the non-carcass components were freeze-dried and analysed for energy, ash, CP and EE. Gross energy content was determined using an adiabatic bomb calorimeter and ash, CP and EE using AOAC (1995) procedures previously described.

2.4. Statistical analysis

All parameters were statistically analysed by one-way analysis of variance. In all statistical analyses, the sums of squares were further partitioned by orthogonal contrasts to determine differences due to treatments. Contrasts were distributed as follows—control *versus* fat: C *versus* LPO, LCaF, HPO and HCaF; level of fat: LPO and LCaF *versus* HPO and HCaF; type of fat: LPO and HPO *versus* LCaF and HCaF. Interaction effects between the level and type of fat were determined. All statistical analyses were completed using the general linear model procedure of SAS (2001).

3. Results

3.1. Apparent digestibility

Inclusion of fat decreased (Table 3) apparent digestibility of ADF (P=0.04) and rations with added fat had higher EE digestibility (P=0.01) (0.525 *versus* 0.438) than control group rations (C *versus* LPO, LCaF, HPO and HCaF).

EE digestibility (contrast LPO and LCaF *versus* HPO and HCaF) increased significantly (P=0.03) when the level of added fat increased (0.727 *versus* 0.814).

The fat level × fat type interaction had a significant effect on the digestibility of organic matter (OM) (P=0.01) and NDF (P=0.03).

Diets with high levels of palm oil (contrast LPO *versus* HPO) presented lower digestibility values (P<0.05) with regard to OM (0.844 in LPO *versus* 0.819 in HPO) and NDF (0.503 in LPO *versus* 0.435 in HPO). Nevertheless, this effect was not observed (P>0.05) when fat was added in the form of calcium soap (contrast LCaF *versus* HCaF).

At the low level of fat inclusion (contrast LPO *versus* LCaF), OM digestibility was greater when fat was in the form of PO than when it was as CaF (0.844 *versus* 0.823, P<0.05). At the high level of fat inclusion (contrast HPO *versus* HCaF), however, NDF digestibility was greater when fat was included in the form of CaF rather than PO (0.435 *versus* 0.500, P>0.05).

3.2. Animal performance

Average daily weight gain (ADG) and days to 25 kg were not affected by the treatments (Table 4). Lambs fed some type of fat supplement (contrast C *versus* LPO, LCaF, HPO and

Table 4
Effect of diet on performance of lambs

	Treatments[a]					S.E.M.[b]	Significance of contrast[b]			
	C	LPO	LCaF	HPO	HCaF		Control *vs.* fat	Level of fat[b]	Type of fat[c]	Level × type of fat
Initial BW (kg)	14.4	14.6	13.9	14.4	14.0	1.56	0.83	0.94	0.39	0.85
ADG[c] (g/day)	263	273	326	292	293	44.5	0.11	0.69	0.15	0.17
Days until 25 kg LW	43	39	35	37	39	9.5	0.23	0.84	0.85	0.52
DMI (g/day)										
Total	823	814	904	832	826	111.5	0.66	0.48	0.33	0.27
Concentrate	760	764	865	783	776	110.9	0.47	0.45	0.31	0.24
Forage	63	50	45	49	50	16.3	0.07	0.78	0.79	0.63
FCR	3.21	2.97	2.81	2.86	2.82	0.333	0.03	0.70	0.48	0.67

[a] Treatment: C, control without fat added; LPO, low level of palm oil; LCaF, low level of calcium soaps of palm oil fatty acids; HPO, high level of palm oil; HCaF, high level of calcium soaps of palm oil fatty acids.
[b] LPO and LCaF *vs.* HPO and HCaF.
[c] LPO and HPO *vs.* LCaF and HCaF.

Table 5
Effect of diet on slaughter weight, empty body weight, hot carcass weight, cold carcass weight, carcass yield and non-carcass weight of lambs

	Treatments[a]					S.E.M.[b]	Significance of contrast			
	C	LPO	LCaF	HPO	HCaF		Control *vs.* fat	Level of fat[b]	Type of fat[c]	Level × type of fat
Slaughter weight (kg)	25.0	25.6	25.5	25.5	25.7	0.99	0.26	0.88	0.96	0.72
Empty body weight (kg)	22.0	22.6	22.6	22.5	22.9	0.88	0.12	0.76	0.47	0.59
Hot carcass weight (kg)	12.3	12.6	12.7	12.7	12.8	0.50	0.09	0.72	0.48	0.86
Cold carcass weight (kg)	12.0	12.2	12.4	12.3	12.4	0.54	0.14	0.83	0.40	0.90
Carcass yield (g/kg)	478	476	487	481	484	1.4	0.52	0.87	0.25	0.47
Non-carcass weight (kg)	9.70	10.00	9.87	9.79	10.16	0.556	0.32	0.87	0.62	0.28

[a] Treatment: C, control without fat added; LPO, low level of palm oil; LCaF, low level of calcium soaps of palm oil fatty acids; HPO, high level of palm oil; HCaF, high level of calcium soaps of palm oil fatty acids.
[b] LPO and LCaF *vs.* HPO and HCaF.
[c] LPO and HPO *vs.* LCaF and HCaF.

HCaF) tended to consume less forage (P=0.07) and had a better FCR than control animals (P=0.03).

3.3. Body composition

Empty body weight, hot carcass weight, cold carcass weight and carcass yield were not affected by the treatments (P>0.05) (Table 5).

Neither the inclusion of fat in the diets or the level or type of fat impacted (P>0.05) any of the chemical composition parameters of the carcass and non-carcass fractions (Table 6).

4. Discussion

Modifications in nutrient digestibility produced by adding fat to fattening rations of ruminants may vary depending on the amount and type of fat used (Clinquart et al., 1995; Doreau and Chilliard, 1997).

Present findings that fat inclusion (contrast C *versus* LPO, LCaF, HPO and HCaF) reduced ADF digestibility concur with data published by Appeddu et al. (2004) and Ramana Reddy et al. (2003), who reported alterations in ruminal degradation of ADF in sheep when calcium soaps of palm oil fatty acids were added to the diet. Nelson et al. (2001) also noted that ADF digestibility decreased when tallow was added to fattening rations of calves.

OM and NDF digestibility were affected by PO level. The lower OM and NDF digestibility values of HPO *versus* LPO diets may indicate that significant alterations in structural

Table 6
Chemical composition (g/kg of fresh weight) and energy content (MJ/kg of fresh weight) of carcass and "non-carcass" fractions of lambs

	Treatments[a]					S.E.M.	Significance of contrast			
	C	LPO	LCaF	HPO	HCaF		Control *vs.* fat	Level of fat[b]	Type of fat[c]	Level × type of fat
Carcass[d]										
Water	631	631	626	610	616	21.4	0.31	0.09	0.90	0.51
Ether extract	166	169	166	182	182	26.6	0.48	0.18	0.88	0.91
Protein	164	161	166	167	164	7.4	0.95	0.48	0.65	0.15
Ash	25	26	32	32	30	8.51	0.21	0.65	0.65	0.24
Energy (MJ/kg)	10.63	10.97	10.72	11.34	11.27	1.068	0.37	0.31	0.71	0.84
Non-carcass fraction[e]										
Water	701	691	712	701	694	18.1	0.89	0.59	0.30	0.07
Ether extract	83	91	73	85	90	17.28	0.88	0.49	0.36	0.11
Protein	185	184	181	186	184	7.7	0.69	0.38	0.44	0.97
Ash	21	22	21	21	22	1.55	0.75	0.29	0.70	0.07
Energy (MJ/kg)	7.72	8.11	7.32	7.69	7.80	0.732	0.97	0.92	0.27	0.15

[a] Treatment: C, control without fat added; LPO, low level of palm oil; LCaF, low level of calcium soaps of palm oil fatty acids; HPO, high level of palm oil; HCaF, high level of calcium soaps of palm oil fatty acids.
[b] LPO and LCaF *vs.* HPO and HCaF.
[c] LPO and HPO *vs.* LCaF and HCaF.
[d] Carcass: chemical composition and energy content of hot carcass estimated from the right half-carcass chemical composition.
[e] The "non-carcass" fraction included the skin, feet, head, internal organs, omental fat, mesenteric fat and empty gastro-intestinal tract of the lambs.

carbohydrate fermentation take place when 41 g/kg of PO are used. Studying the effects of adding different levels of tallow in the barley finishing diets of wethers, Nelson et al. (2001) observed that NDF digestibility was lowest when the amount of tallow added was 40 g/kg.

The lack of differences in OM and NDF digestibility values between diets with high and low levels of CaF (LCaF *versus* HCaF) indicates that ruminal alterations do not occur when fat is included in the form of calcium soap. The association of Ca and fatty acids in the form of soap is thought to be inert in the rumen (Jenkins, 1993). This concurs with our statistics that show that NDF digestibility was significantly greater ($P<0.05$) with HCaF diets than with HPO rations. Nevertheless, differences in NDF digestibility between PO and CaF diets were not significant when low levels of fat (LPO *versus* LCaF) were used. These results could indicate that low levels of PO (25 g/kg) did not negatively affect ruminal digestion (differences between the control group and LPO and LCaF groups were not statistically significant, $P>0.05$).

We have found no bibliographic data to explain why OM digestibility coefficients are lower with LCaF than with LPO. Lambs fed LCaF had higher DMI values than lambs fed LPO, and nutrient digestibility may decrease when DMI increases (Nigdi et al., 1990;

Haddad and Younis, 2004; Weiss and Wyatt, 2004). The low number of animals per treatment and the large standard error could be responsible for the statistically significant differences between DMI values of lambs fed LCaF and those given LPO.

The increase in EE digestibility when fat is added to the diet is consistent with the findings of Grummer (1988), Schneider et al. (1988), Ramana Reddy et al. (2003) and Weiss and Wyatt (2004). These authors suggested that EE digestibility increases because the added fat is characterised by greater digestibility and availability than the fatty acids within food particles, and because endogenous fat losses are diluted by the increment in the level of fat in the ration. Fatty acid profiles of PO and CaF were similar (Table 1), which may explain the lack of differences resulting from the types of fat used.

DMI, ADG and FCR values in this study are comparable to those of other studies with lambs raised under similar conditions (*e.g.* Manso et al., 1998; Preziuso et al., 1999). The lack of change in DMI is consistent with Preziuso et al. (1999), Ivan et al. (2001), Rizzi et al. (2002), Kott et al. (2003) and Demirel et al. (2004), who reported no reduction in DMI when various vegetable fats were included in lamb rations. In contrast, Haddad and Younis (2004) reported a decrease in DMI after adding 25 and 50 g/kg of saturated fat (ULTRALAC^{TM} 100) to Awassi lamb diets. Lough et al. (1993) also observed a decrease in DMI when 100 g/kg palm oil was included in the ration. However, diets compared by Haddad and Younis (2004) and Lough et al. (1993) were not isoenergetic and the lambs reached the same energy intake levels with reduced DM intake.

Some authors have reported apparent palatability problems with calcium soaps in steers (Zinn, 1989; Nigdi et al., 1990; Chilliard and Ollier, 1994). This effect was not evident in lambs in the present experiment, possibly because all diets included an aroma (APENZIMA 6, NOREL SA, Madrid, Spain).

The FCR was lower in lambs fed a palm oil or calcium soap supplement, which concurs with the results of Lough et al. (1993), who recorded lower feed conversion rates in lambs fed a dietary palm oil supplement. Other authors (Kott et al., 2003; Rizzi et al., 2002), using isoenergetic and isonitrogenous diets, have also observed improved feed conversion ratios in lambs fed dietary supplements consisting of vegetable oils from different sources. The partial change of carbohydrates for fat may lead to greater efficiency in the use of ME, as energy losses due to ruminal fermentation are reduced (Machmüller et al., 2000). The lack of differences between the FCR of lambs given both levels and types of fat may be explained by the absence of important differences in the digestion of the diets.

A number of authors have noted that the inclusion of fat in fattening diets may increase carcass yield due to greater carcass fatness (Zinn, 1989; Clinquart et al., 1995). No differences in the carcass yield and body chemical composition between experimental treatments were found in this study. Ivan et al. (2001) and Kott et al. (2003) noted similar results after adding various fats to lamb diets. However, these results contrast with those of Solomon et al. (1992) and Lough et al. (1993), who found that supplementation with 100 g PO/kg resulted in greater fat deposition, probably caused by elevated intake and high daily weight gain. The levels of fat used in this study (below 50 g/kg) and the absence of significant differences in intake and weight gain between the different experimental treatments could explain the lack of differences in carcass yield and body composition. In addition, lambs in the present trial were slaughtered at early stages of maturity and diet affects fatness most during late stages of growth (Butterfield, 1988).

5. Conclusions

Inclusion of up to 41 g of fat from palm oil or calcium soaps of palm oil fatty acids per kilogram of the concentrate of growing lambs improves EE digestibility and the feed conversion ratio without affecting carcass yield and body chemical composition.

Inclusion of palm oil fatty acids as calcium soaps avoided the negative effects on fibre digestibility observed when 41 g PO/kg were added to the diet.

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References

AOAC, 1995. Official Methods of Analysis of the Association of Official Agricultural Chemists, 16th ed. AOAC, Washington, DC, USA.

Appeddu, L.A., Ely, D.G., Aaron, D.K., Deweese, W.P., Fink, E., 2004. Effects of supplementing with calcium salts of palm oil fatty acids or hydogenated tallow on ewe milk production and twin lamb growth. J. Anim. Sci. 82, 2780–2789.

Bas, P., Morand-Fehr, P., 2000. Effect of nutritional factors on fatty acid composition of lamb fat deposits. Livest. Prod. Sci. 64, 61–79.

Beaulieu, A.D., Drackley, J.K., Merchen, N.R., 2002. Concentrations of conjugated linoleic acid (*cis*-9, *trans*-11-octadecadienoic acid) are not increased in tissue lipids of cattle fed a high-concentrate diet supplemented with soybean oil. J. Anim. Sci. 80, 847–861.

Butterfield, R.M., 1988. New Concepts of Sheep Growth. University of Sidney, Sidney, NSW, Australia.

Chilliard, Y., Ollier, A., 1994. Alimentation lipidique et metabolisme du tissu adipeux chez les ruminants. Comparison avec le porc et les rongeurs. INRA Prod. Anim. 7 (4), 293–308.

Chilliard, Y., 1993. Dietary fat and adipose tissue metabolism in ruminants, pigs, and rodents: a review. J. Dairy Sci. 76, 3897–3931.

Clinquart, A., Micol, D., Brundseaux, C., Dufrasne, I., Istasse, L., 1995. Utilisation des matières grasses chez les bovins à l'engraissement. INRA Prod. Anim. 8 (1), 29–42.

Demirel, G., Wachira, A.M., Sinclair, L.A., Wilkinson, R.G., Wood, J.D., Enser, M., 2004. Effects of dietary n-3 polyunsaturated fatty acids, breed and dietary Vitamin E on the fatty acids of lamb muscle, liver and adipose tissue. Br. J. Nutr. 91, 551–565.

Doreau, M., Chilliard, Y., 1997. Digestion and metabolism of dietary fat in farm animals. Br. J. Nutr. 78, S15–S35.

Duckett, S.K., Andrae, J.G., Owens, F.N., 2002. Effect of high-oil corn or added corn oil on ruminal biohydrogenation of fatty acids and conjugated linoleic acid formation in beef steers fed finishing diets. J. Anim. Sci. 80, 3353–3360.

FEDNA, 1999. Normas FEDNA para la formulación de piensos compuestos. Fundación española para el desarrollo de la nutrición animal, Madrid.

Grummer, R.R., 1988. Influence of prilled fat and calcium salts of palm oil fatty acids on ruminal fermentation and nutrient digestibility. J. Dairy Sci. 71, 117–123.

Haddad, S.G., Younis, H.M., 2004. The effect of adding ruminally protected fat in fattening diets on nutrient intake, digestibility and growth performance of Awassi lambs. Anim. Feed Sci. Technol. 113, 61–69.

Ivan, M., Mir, P.S., Koenig, K.M., Rode, L.M., Neill, L., Mir, Z., 2001. Effects of dietary sunflower seed oil on rumen protozoa population and tissue concentration of conjugated linoleic acid in sheep. Small Rumin. Res. 41, 215–227.

Ivan, M., Mir, P.S., Mir, Z., Entz, T., He, M.L., McAllister, T.A., 2004. Effects of dietary sunflower seeds on rumen protozoa and growth of lambs. Br. J. Nutr. 92, 303–310.

Jenkins, T.C., 1993. Lipid metabolism in the rumen. J. Dairy Sci. 76, 3851–3863.

Kott, R.W., Hatfield, P.G., Bergman, J.W., Flynn, C.R., Van Wagoner, H., Boles, J.A., 2003. Feedlot performance, carcass composition, and muscle and fat CLA concentration of lambs fed diets supplemented with safflower seeds. Small Rumin. Res. 41, 11–17.

Lough, D.S., Solomon, M.B., Rumsey, T.S., Kahl, S., Slyter, L.L., 1993. Effects of high-forage diets with added palm oil on performance, plasma lipids, and carcass characteristics of ram and ewe lambs. J. Anim. Sci. 71, 1171–1176.

Machmüller, A., Ossowski, D.A., Kreuzer, M., 2000. Comparative evaluation of the effects of coconut oil, oilseeds and crystalline fat on methane release, digestion and energy balance in lambs. Anim. Feed Sci. Technol. 85, 41–60.

Manso, T., Mantecón, A.R., Giráldez, F.J., Lavín, P., Castro, T., 1998. Animal performance and chemical body composition of lambs fed diets with different protein supplements. Small Rumin. Res. 29, 185–191.

Moibi, J.A., Christopherson, R.J., 2001. Effect of environmental temperature and a protected lipid supplement on the fatty acid profile of ovine longissimus dorsi muscle, liver and adipose tissues. Livest. Prod. Sci. 69, 245–254.

Nelson, M.L., Westberg, H.H., Parish, S.M., 2001. Effects of tallow on the energy metabolism of wethers fed barley finishing diets. J. Anim. Sci. 79, 1892–1904.

Nigdi, M.E., Loerch, S.C., Fluharly, F.L., Palmquist, D.L., 1990. Effects of calcium soaps of long-chain fatty acids on feedlot performance, carcass characteristics and ruminal metabolism of steers. J. Anim. Sci. 68, 2555–2565.

Perez, J.M., Bories, G., Aumaitre, A., Barrier-Guillot, B., Delaveau, A., Gueguen, L., Larbier, M., Sauvant, D., 2002. Consèquences en èlevage et pour le consommateur du remplacement des farines et des graisses animals. INRA Prod. Anim. 15, 87–96.

Preziuso, G., Russo, C., Casarosa, L., Campodoni, G., Pilón, S., Cianci, D., 1999. Effect of diet energy source on weight gain and carcass characteristics of lambs. Small Rumin. Res. 33, 9–15.

Ramana Reddy, Y., Krishna, N., Raghava Rao, E., Janardhana Reddy, T., 2003. Influence of dietary protected lipids on intake and digestibility of straw based diets in Deccani sheep. Anim. Feed Sci. Technol. 106, 29–38.

Rizzi, L., Simioli, M., Sardi, L., Monetti, P.G., 2002. Carcass quality, meat chemical and fatty acid composition of lambs fed diets containing extruded soybeans and sunflower seeds. Anim. Feed Sci. Technol. 97, 103–114.

Russo, C., Preziuso, G., Casarosa, L., Campodoni, G., Ciani, D., 1999. Effect of diet energy source on the chemical–physical characteristics of meat and depot fat of lambs carcasses. Small Rumin. Res. 33, 77–85.

Sauvant, D., Bas, P., 2001. La digestion des lipides chez le ruminant. INRA Prod. Anim. 14 (5), 303–310.

SAS (Statistical Analysis System Institute), 2001. SAS Companion for the Microsoft Windows Environment, Version 6.12. SAS Institute Inc., Cary, NC, USA.

Schneider, P., Sklan, D., Chalupa, W., Kronfeld, D.S., 1988. Feeding calcium salts of fatty acids to lactating cows. J. Dairy Sci. 71, 2143–2150.

Solomon, M.B., Lynch, G.P., Lough, D.S., 1992. Influence of dietary palm oil supplementation on serum lipid metabolites, carcass characteristics and lipid composition of carcass tissues of growing ram and ewe lambs. J. Anim. Sci. 70, 2746–2751.

Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74, 3583–3597.

Weiss, W.P., Wyatt, D.J., 2004. Digestible energy values of diets with different fat supplements when fed to lactating dairy cows. J. Dairy Sci. 87, 1446–1454.

Zinn, R.A., 1989. Influence of level and source of dietary fat on its comparative feeding value in finishing diets for steers: feedlot cattle growth and performance. J. Anim. Sci. 67, 1029–1037.