Effects of feeding increasing dietary levels of high oleic or regular sunflower or linseed oil on fatty acid profile of goat milk

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ABSTRACT

In this work, the effects of increasing amounts of 3 plant oils in diets on the fatty acid (FA) profile of goat milk were studied. The study consisted of 3 experiments, one per oil tested (linseed oil, LO; high oleic sunflower oil, HOSFO; and regular sunflower oil, RSFO). The 3 experiments were conducted successively on 12 Malagueña goats, which were assigned at random to 1 of 4 treatments: 0, 30, 48, and 66 (H) g of added oil/d. A basal diet made of alfalfa hay and pelleted concentrate (33:67) was used in all of the experiments. For each animal, milk samples collected after 15 d on treatments were analyzed for fat, protein, lactose, and FA composition, whereas individual milk yield was measured the last 3 d of each experiment. Oil supplementation affected neither dry matter intake nor milk production traits. Increasing the oil supplementation decreased the content of saturated FA (especially 16:0) in milk fat and increased mono- and polyunsaturated FA in a linear manner. Vaccenic acid content linearly increased with the oil supplementation by 370, 217, and 634% to 5.32, 2.66, and 5.09 g/100 g of total FA methyl esters with the H diet in LO, HOSFO, and RSFO experiments, respectively. Rumenic acid content linearly increased with LO and RSFO supplementation by 298 and 354% from 0.53 and 0.41 g/100 g of total FA methyl esters with the 0 g of added oil/d diet. The content of *trans*-10-18:1 was not affected by LO supplementation but showed an increasing linear trend with HOSFO supplementation and linearly increased with RSFO supplementation. The ratio of n-6 to n-3 polyunsaturated FA in milk fat was decreased by about 70% with the H diet in the LO experiment and it was increased by 54 and 82% with the H diet in the HOSFO and

RSFO experiments. In conclusion, LO supplementation in this work seemed to be the most favorable alternative compared with HOSFO or RSFO supplementation. **Key words:** fatty acid, goat milk, rumenic acid, vaccenic acid, plant oil

INTRODUCTION

It is well known that the FA profile in milk and meat from ruminant animals can be modified with appropriate dietary fat sources to get products richer in specific FA (Collomb et al., 2006; Givens et al., 2006). Among such FA, n-3 FA, mostly represented by α -linolenic acid in milk fat, are commonly found in very low quantities in dairy products. In contrast, *cis*(c)-9,*trans*(t)-11-18:2 (rumenic acid, **RA**), an isomer of conjugated linoleic acid (**CLA**) with potentially healthy properties, is distinctive as it is produced naturally in ruminants, from rumen metabolism of dietary PUFA, or from tissue desaturation of *t*-11-18:1 (vaccenic acid, **VA**). In addition, it has been demonstrated that VA consumption can increase serum RA in humans (Turpeinen et al., 2002) and milk RA in lactating women (Mosley et al., 2006), and the literature suggests that VA has health benefits beyond those associated with being the only known precursor of RA (Field et al., 2009).

The approach to improve the FA profile in milk from nongrazing dairy ruminants is to add oilseeds or plant oils rich in unsaturated fatty acids (**UFA**) to the diet. However, this supplementation could also increase the milk content of some FA such as *t*-9- and *t*-10-18:1 (Bernard et al., 2009c), which are deemed undesirable for human consumption (Hodgson et al., 1996). Furthermore, Roy et al. (2007) have found that *t*-10-18:1 has detrimental effects on plasma lipids in lipoprotein metabolism in rabbits.

Extensive research has been conducted in dairy cows to investigate the effect of different plant oils on milk FA profile (Collomb et al., 2004; Bu et al., 2007). Available results point out that the milk FA response to the inclusion of unsaturated plant oils in the diet of dairy goats could be different from that observed in dairy

Received February 24, 2011.

Accepted November 26, 2011.

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cows (Chilliard et al., 2003; Bernard et al., 2009a,b). Furthermore, most of the research has been carried out on high-yielding goat breeds (Chilliard et al., 2003; Chilliard and Ferlay, 2004) or has been focused on a limited number of milk FA with indigenous breeds of goats (Bouattour et al., 2008).

Increasing the milk content of RA and VA through the addition of plant oils to goat diets and decreasing SFA as well as n-6/n-3 ratio could add extra value to dairy products. However, it is important to know not only which vegetable oil promotes the highest increase of those FA but also to gather information on the level of added oil that produces the desired effects. The aim of this work was to study the change of the FA profile in goat milk when increasing amounts of 3 different plant oils were added to the diet.

MATERIALS AND METHODS

Animals, Housing, and General Management

The experiments were carried out on the premises of the Animal Production building of the University of Córdoba (Córdoba, Spain), in accordance with the Spanish regulation on experimental animals. The same 12 multiparous Malagueña goats (70, 85, and 100 DIM

at the beginning of experiments 1, 2, and 3 respectively, and 46.6 ± 3.7 kg of initial BW) were used in each experiment. The animals were in a room at $24 \pm 1^\circ\text{C}$ temperature and 16 h of light. They were placed in individual cages of 1.0×1.4 m with slatted floor and water and feeding troughs. Before the experiment, all the animals were vaccinated against contagious agalactia, gangrenous mastitis, clostridium enterotoxemia, and hemorrhagic septicemia (Laboratorios Ovejero SA, León, Spain). The goats were machine milked and stripped out by hand once per day at 0830 h. The diet was offered in 2 equal meals at 0930 and 1600 h.

Experimental Design and Diets

Three experiments were arranged, one per oil tested: linseed oil (**LO**, experiment 1), high oleic sunflower oil (**HOSFO**, experiment 2), and regular sunflower oil (**RSFO**, experiment 3). The design was the same for the 3 experiments (Table 1). It consisted of 4 treatments: no added oil (control treatment, **C** diet), and 3 levels of oil addition, 30 g/d (low-level treatment, **L** diet), 48 g/d (medium-level treatment, **M** diet), and 66 g/d (high-level treatment, **H** diet). The same goats were used in each experiment. Within and at the beginning of each experiment, each treatment was allocated

Table 1. Ingredients, chemical composition, and oil FA supply of the experimental diets

Item	Control diet ¹	Experiment ²								
		LO diet			HOSFO diet			RSFO diet		
		L	M	H	L	M	H	L	M	H
Diet (g/d)										
Alfalfa hay	600		600			600			600	
Concentrate ³	1,200		1,200			1,200			1,200	
LO ⁴	—	30	48	66	—	—	—	—	—	—
HOSFO ⁴	—	—	—	—	30	48	66	—	—	—
RSFO ⁴	—	—	—	—	—	—	—	30	48	66
Chemical composition										
DM (%)	91.2	91.1	91.5	91.9	90.8	91.4	91.2	91.4	91.2	91.0
CP (% DM)	16.7	16.3	16.3	15.9	16.2	15.9	16.0	16.3	16.2	16.0
NDF (% DM)	28.1	26.9	26.9	26.1	27.5	27.5	27.1	27.7	27.1	27.2
Fat ⁵ (% DM)	3.1	4.9	5.7	6.8	4.6	5.4	6.7	4.7	5.5	6.6
Ash (% DM)	7.4	7.3	6.6	7.1	7.4	7.5	7.2	7.5	7.2	7.3
FA from oil (g/d)										
16:0	—	1.6	2.6	3.5	1.1	1.8	2.5	1.8	2.9	4.0
18:0	—	1.2	1.8	2.5	0.9	1.4	2.0	1.3	2.0	2.8
<i>cis</i> -9-18:1	—	6.3	10.0	13.8	25.6	41.0	56.3	8.9	14.2	19.5
18:2n-6	—	5.0	8.0	11.0	1.7	2.7	3.7	17.4	27.9	38.3
18:3n-3	—	15.0	23.9	32.9	—	—	—	—	—	—

¹Control diet supplied 5.1, 0.8, 6.9, 18.9, and 6.5 g/d of 16:0, 18:0, *cis*-9-18:1, 18:2n-6, and 18:3n-3, respectively, calculated according to INRA (2002). This diet was included in all 3 experiments.

²LO = linseed oil, HOSFO = high oleic sunflower oil, RSFO = regular sunflower oil, and L = low, M = medium, and H = high oil supplementation.

³Composition (g/kg, as fed): maize, 375.0; barley, 374.9; soybean meal, 200.0; vitamin and mineral premix (Maxi Nutral Ovejas; Nutral SA, Madrid, Spain), 30.0; binder (Exal; Tolsa SA, Madrid, Spain), 20.0; antioxidant (Luctanox; Lucta SA, Barcelona, Spain), 0.1.

⁴The oils were included in the respective concentrate.

⁵Fat by acid hydrolysis.

Table 2. Dry matter intake, milk yield, and milk composition of lactating dairy goats fed none (C), 30 (L), 48 (M), and 66 (H) g/d of linseed oil (LO), high oleic sunflower oil (HOSFO), or regular sunflower oil (RSFO)

Item	Experiment ¹														
	LO					HOSFO					RSFO				
	C	L	M	H	SEM	C	L	M	H	SEM	C	L	M	H	SEM
DMI (g/d)	1,610	1,598	1,622	1,488	27	1,600	1,630	1,657	1,663	15	1,614	1,508	1,633	1,580	29
Milk															
Yield (g/d)	1,507	1,870	2,035	1,573	183	1,437	1,583	1,530	2,095	180	1,615	1,233	1,580	1,250	124
Fat (%)	5.95	5.21	4.52	4.68	0.29	5.50	4.96	5.59	4.61	0.24	4.67	5.92	6.10	4.64	0.32
Fat (g/d)	90	95	89	72	10	78	73	81	93	8	73	70	93	53	7
Protein (%)	3.23	3.07	3.00	3.26	0.07	3.55	3.30	3.27	3.05	0.10	3.13	3.65	2.92	3.41	0.14
Protein (g/d)	47	56	59	49	5	50	50	46	63	5	49	44	44	42	4
Lactose (%)	4.59	4.37	4.39	4.65	0.07	4.43	4.51	4.51	4.35	0.04	4.41	4.48	4.52	4.34	0.06
Lactose (g/d)	66	79	87	70	8	61	69	67	88	8	69	52	69	53	5

¹Linear, quadratic, and cubic effects were nonsignificant ($P > 0.05$).

to 3 goats, at random, and lasted 15 d. According to different studies (Chilliard et al., 2007), this time would be enough to get responses of FA in milk fat not different of those obtained with longer periods.

Equal amounts of the same basal diet were used across treatments and experiments (Table 1). It consisted of 33:67 alfalfa hay-pelleted concentrate. To get the aimed oil intakes, convenient amounts of the 3 oils were added to the concentrate mix before pelleting. Pelleted concentrates were kept in plastic bags at 4°C until fed to the animals.

Measurements, Sample Collection, and Chemical Analysis

Voluntary feed intake was recorded daily for each animal. Daily DMI was calculated as the difference between DM in offered feed and orts. The ingredients of the diets were sampled at the beginning of each experiment and stored, as well as the orts, at −20°C until analysis. The procedures described by AOAC (2006) were used to measure DM in feeds and orts (method 930.15), and ash (method 942.05), CP (method 984.13), and fat by acid hydrolysis in feeds (method 954.02). Neutral detergent fiber was measured in feeds by the method described by Van Soest et al. (1991). Samples of the 3 plant oils used were methylated with sodium methoxide/trifluoride, extracted with isooctane, and injected in a gas chromatograph (Agilent 6890 N Network System; Agilent Technologies Inc., Palo Alto, CA) with autoinjector and fitted with a flame ionization detector. The profile of FA methyl esters (**FAME**) was determined by split injection (1:50) onto a SupelcoW-axsemicapillary column (30 m × 0.53 mm i.d., 1.00-μm film thickness; Supelco Inc., Bellefonte, PA) using a programmed temperature method. The initial oven temperature was 175°C. After 2 min, the oven temperature was raised at 8°C min^{−1} to 235°C and then held for 8 min. Helium was the carrier gas and the injector and detector were at 250°C.

Three samples of milk were taken from each animal at d 15, one for chemical composition (Milko-Scan FT120; Foss Electric A/S, Hillerød, Denmark) and the others for FA analysis. Individual milk yield was recorded in the last 3 d of each experiment. Daily milk was weighed and expressed on a 24-h basis.

To analyze FA composition, milk fat was extracted following the procedure described by Luna et al. (2005). Separated lipids were stored in amber vials, blanketed with a stream of N₂, and stored at −20°C until analysis. Fatty acid methyl esters were prepared by base-catalyzed methanolysis of the glycerides (ISO-IDF 2002a). Analysis of FAME in hexane was performed on a gas chromatograph (Agilent 6890 N Network System;

Table 3. Experiment 1: milk FA profile (g/100 g of total FA methyl esters) determined by gas chromatography of lactating dairy goats fed none (C), 30 (L), 48 (M), and 66 (H) g/d of linseed oil

Item ¹	Treatment				SEM	Effect ²	
	C	L	M	H		Linear	Quadratic
SFA							
4:0	2.46	2.76 ^a	2.94 ^a	2.72	0.063	<0.01	<0.05
5:0	0.017	0.019	0.021	0.055	0.008	NS	NS
6:0	2.73	3.30 ^a	3.34 ^a	2.95	0.088	<0.01	<0.001
7:0	0.033	0.039	0.036	0.102	0.014	NS	NS
8:0	2.95	3.82 ^a	3.67 ^a	3.19	0.127	NS	<0.01
4-Methyl octanoate	0.034	0.043	0.033	0.085	0.011	NS	NS
9:0	0.066	0.079	0.070	0.184	0.025	NS	NS
10:0	11.14	12.40	11.04	9.91	0.407	NS	NS
Methyl decanoate	0.052	0.057	0.044	0.115	0.014	NS	NS
12:0	4.93	4.36	3.87	3.58	0.297	NS	NS
Methyl dodecanoate	0.021	0.021	0.017	0.036	0.004	NS	NS
13:0 <i>iso</i>	0.027	0.013	0.012	0.019	0.004	NS	NS
13:0 <i>anteiso</i>	0.041	0.030	0.034	0.028	0.003	NS	NS
14:0 <i>iso</i>	0.049	0.034	0.045	0.047	0.004	NS	NS
14:0	10.21	8.86	8.82	7.82	0.400	<0.05	NS
Methyl tetradecanoate	0.046	0.048	0.037	0.088	0.010	NS	NS
15:0 <i>iso</i>	0.146	0.116	0.118	0.122	0.008	NS	NS
15:0 <i>anteiso</i>	0.292	0.199	0.247	0.316	0.023	NS	NS
15:0	0.711	0.598	0.676	0.984	0.085	NS	NS
16:0 <i>iso</i>	0.140	0.090	0.160	0.127	0.011	NS	NS
16:0	33.77	26.25	24.49 ^a	22.39 ^a	1.761	<0.01	NS
17:0	0.399	0.345	0.343	0.448	0.027	NS	NS
18:0 <i>iso</i>	0.034	0.033	0.036	0.029	0.002	NS	NS
10-keto 18:0	0.038	0.061	0.094	0.158 ^a	0.019	<0.05	NS
18:0	7.02	9.88 ^a	7.80	8.46	0.419	NS	NS
19:0	0.011	0.045 ^a	0.045 ^a	0.046 ^a	0.006	<0.001	<0.05
20:0	0.113	0.121	0.113	0.114	0.004	NS	NS
21:0	0.029	0.021	0.024	0.022	0.002	NS	NS
22:0	0.064	0.051	0.056	0.055	0.003	NS	NS
MUFA							
<i>c</i> -9-10:1/12:0 <i>iso</i> /11:0	0.276	0.313	0.339	0.371	0.025	NS	NS
<i>c</i> -9-12:1/13:0	0.158	0.130	0.134	0.189	0.016	NS	NS
<i>c</i> -9-14:1	0.136	0.098	0.125	0.093	0.010	NS	NS
<i>c</i> -9-15:1	0.056	0.061	0.058	0.049	0.004	NS	NS
<i>t</i> -8-16:1	0.051	0.068	0.080	0.076	0.007	NS	NS
<i>t</i> -9-16:1/17:0 <i>iso</i>	0.351	0.464	0.601	0.699	0.060	<0.05	NS
<i>c</i> -7-16:1	0.258	0.269	0.304	0.275	0.013	NS	NS
<i>c</i> -8-16:1	0.010	0.029 ^a	0.039 ^a	0.036 ^a	0.004	<0.001	NS
<i>c</i> -9-16:1/17:0 <i>anteiso</i>	1.05	0.721 ^a	0.800 ^a	0.787 ^a	0.047	<0.01	<0.05
<i>c</i> -13-16:1	0.180	0.148	0.157	0.115	0.015	NS	NS
<i>c</i> -9-17:1	0.177	0.118 ^a	0.131 ^a	0.124 ^a	0.009	<0.05	NS
<i>t</i> -4-18:1	0.017	0.023	0.024	0.032	0.003	NS	NS
<i>t</i> -5-18:1	0.018	0.025	0.024	0.030	0.003	NS	NS
<i>t</i> -6/ <i>t</i> -7/ <i>t</i> -8-18:1	0.185	0.292	0.315	0.434 ^a	0.036	<0.01	NS
<i>t</i> -9-18:1	0.195	0.274	0.333	0.438 ^a	0.036	<0.01	NS
<i>t</i> -10-18:1	0.283	0.500	0.432	0.551	0.058	NS	NS
<i>t</i> -11-18:1	1.14	2.59	3.53	5.32 ^a	0.592	<0.01	NS
<i>t</i> -12-18:1	0.198	0.394 ^a	0.455 ^a	0.557 ^a	0.050	<0.001	NS
<i>c</i> -9-18:1	13.72	13.94	15.06	14.52	0.442	NS	NS
<i>t</i> -15/ <i>c</i> -11-18:1	0.322	0.517	0.645	0.875 ^a	0.080	<0.01	NS
<i>c</i> -12-18:1	0.152	0.347	0.491	0.706	0.102	<0.05	NS
<i>c</i> -13-18:1	0.037	0.051	0.072 ^a	0.074 ^a	0.006	<0.01	NS
<i>t</i> -16/ <i>c</i> -14-18:1	0.193	0.436 ^a	0.459 ^a	0.589 ^a	0.054	<0.001	NS
<i>c</i> -15-18:1	0.054	0.192	0.365 ^a	0.528 ^a	0.067	<0.001	NS
<i>c</i> -16-18:1	0.023	0.040	0.034	0.035	0.003	NS	NS
<i>c</i> -11-20:1	0.042	0.047	0.046	0.057	0.003	<0.05	NS
Nonconjugated C18:2							
<i>t</i> -11, <i>t</i> -15-18:2	0.043	0.030	0.065	0.117 ^a	0.013	<0.01	<0.05
<i>t</i> -9, <i>t</i> -12/ <i>c</i> -9, <i>t</i> -13/ <i>t</i> -8, <i>c</i> -12-18:2	0.162	0.262	0.413	0.400	0.043	<0.05	NS
<i>t</i> -8, <i>c</i> -13-18:2	0.056	0.105	0.160 ^a	0.173 ^a	0.019	<0.01	NS
<i>c</i> -9, <i>t</i> -12-18:2	0.027	0.031	0.043	0.051	0.005	NS	NS
<i>t</i> -9, <i>c</i> -12-18:2	0.030	0.032	0.048	0.082 ^a	0.008	<0.01	NS
<i>t</i> -11, <i>c</i> -15-18:2	0.036	0.360	0.949	1.63 ^a	0.236	<0.01	NS

Continued

Table 3 (Continued). Experiment 1: milk FA profile (g/100 g of total FA methyl esters) determined by gas chromatography of lactating dairy goats fed none (C), 30 (L), 48 (M), and 66 (H) g/d of linseed oil

Item ¹	Treatment				SEM	Effect ²	
	C	L	M	H		Linear	Quadratic
<i>c</i> -9, <i>c</i> -12-18:2	1.66	1.57	1.93	1.93	0.122	NS	NS
Other 18:2	0.047	0.065	0.079	0.135 ^a	0.013	<0.001	<0.05
Conjugated C18:2							
<i>c</i> -9, <i>t</i> -11-18:2	0.525	0.876	1.73	2.09 ^a	0.258	<0.01	NS
<i>t</i> -9, <i>c</i> -11-18:2	0.011	0.014	0.021	0.018	0.002	NS	NS
<i>t</i> -10, <i>c</i> -12-18:2	0.007	0.008	0.008	0.011	0.001	NS	NS
<i>t</i> -11, <i>c</i> -13-18:2	0.010	0.017	0.018	0.029 ^a	0.003	<0.05	NS
<i>t</i> -12, <i>t</i> -14-18:2	0.008	0.011	0.015	0.027	0.004	<0.05	NS
<i>t</i> -11, <i>t</i> -13-18:2	0.006	0.009	0.014	0.019 ^a	0.002	<0.01	NS
<i>t</i> -9, <i>t</i> -11-18:2	0.012	0.015	0.020	0.033 ^a	0.003	<0.01	NS
Other PUFA							
16:2	0.008	0.024	0.057	0.085 ^a	0.012	<0.01	NS
18:3n-6	0.026	0.045	0.034	0.042	0.005	NS	NS
18:3n-3	0.181	0.427	0.661	0.819 ^a	0.105	<0.05	NS
<i>c</i> -9, <i>t</i> -11, <i>t</i> -15-18:3	0.007	0.019	0.047 ^a	0.071 ^a	0.009	<0.001	NS
<i>c</i> -9, <i>t</i> -11, <i>c</i> -15-18:3	0.040	0.055	0.103	0.193	0.028	<0.05	NS
20:2n-6	0.010	0.010	0.014	0.013	0.001	<0.05	NS
20:3n-3	0.009	0.009	0.006	0.011	0.001	NS	NS
20:4n-6	0.133	0.105	0.120	0.112	0.006	NS	NS
20:5n-3	0.022	0.033	0.043	0.042	0.004	<0.05	NS
22:4n-6	0.023	0.025	0.033	0.036	0.004	NS	NS
22:5n-3	0.034	0.054	0.047	0.043	0.004	NS	NS
22:6n-3	0.017	0.017	0.012	0.012	0.002	NS	NS
ΣSFA	77.70	73.79	68.35	64.34 ^a	2.066	<0.01	NS
ΣMUFA	19.12	21.95	24.93	27.38 ^a	1.289	<0.01	NS
ΣPUFA	3.18	4.26	6.72	8.29 ^a	0.805	<0.01	NS
Σ <i>t</i> -18:1	2.55	5.05	6.22	8.83 ^a	0.887	<0.01	NS
ΣCLA	0.580	0.950	1.82	2.22 ^a	0.268	<0.01	NS
Atherogenicity index ³	3.61	2.52	2.10 ^a	1.63 ^a	0.293	<0.01	NS
n-6/n-3 PUFA ⁴	6.03	2.88 ^a	2.30 ^a	1.85 ^a	0.597	<0.001	<0.05
<i>c</i> -9-14:1/14:0 + <i>c</i> -9-14:1	0.013	0.011	0.014	0.016	0.001	NS	NS
<i>c</i> -9-18:1/18:0 + <i>c</i> -9-18:1	0.661	0.586	0.657	0.632	0.013	NS	NS

^aValues for oil-supplemented diets within rows with the “a” superscript are significantly different from values for the control diet ($P < 0.05$).

¹*c* = *cis*; *t* = *trans*; CLA = conjugated linoleic acid.

²Cubic effect was not significant ($P > 0.05$).

³Ulbricht and Southgate (1991): $(12:0 + 4 \times 14:0 + 16:0)/(\text{MUFA} + \text{PUFA})$.

⁴n-6: *c*-9,*c*-12-18:2 + 18:3n-6 + 20:2n-6 + 20:4n-6 + 22:4n-6; n-3: 18:3n-3 + *c*-9,*t*-11,*t*-15-18:3 + *c*-9,*t*-11,*c*-15-18:3 + 20:3n-3 + 20:5n-3 + 22:5n-3 + 22:6n-3.

Agilent Technologies Inc.) with autoinjector and fitted with a flame-ionization detector. The FAME profile was determined by split injection (1:100) onto a CP-Sil 88 fused silica capillary column (100 m × 0.25 mm i.d., 0.20-μm film thickness; Varian Inc., Middelburg, the Netherlands) using a programmed temperature method. The initial oven temperature was 160°C. After 80 min, the oven temperature was raised at 10°C min⁻¹ to 210°C and then held for 35 min. Helium was the carrier gas and the injector and detector were at 250°C.

Quantification of individual FAME was made by reference to a milk fat with a certified composition (CRM 164; European Community Bureau of Reference, Brussels, Belgium) according to the International Organization for Standardization-International Dairy Federation (ISO-IDF, 2002b). Individual isomers of CLA were identified by comparison to standard mixtures distributed

by Nu-Chek Prep Inc. (Elysian, MN); GLC-461 from Nu-Chek Prep Inc. was also used to identify other FA.

Statistical Analyses

Data were analyzed using the GLM procedure of SAS (SAS Institute, 2004). The response to oil levels was investigated through preplanned polynomial contrasts. The model was $Y_{ij} = \mu + T_i + \varepsilon_{ij}$, where Y_{ij} is the observation (DMI, milk, fat, protein, lactose, and FAME contents), μ is the overall mean, T_i is the fixed effect of treatment ($i = 4$), and ε_{ij} is the random residual. Additionally, means from the diets with added oil were compared with the control diet using the Dunnett test. Correlations between the daily intake of plant oils and selected FA were investigated with the SAS CORR procedure. Statistical significance was declared at $P < 0.05$.

Table 4. Experiment 2: milk FA profile (g/100 g of total FA methyl esters) determined by gas chromatography of lactating dairy goats fed none (C), 30 (L), 48 (M), and 66 (H) g/d of high oleic sunflower oil

Item ¹	Treatment				SEM	Effect	
	C	L	M	H		Linear	Quadratic
SFA							
4:0 ²	2.32	2.68 ^a	2.50	2.72 ^a	0.060	<0.05	NS
5:0 ²	0.016	0.028	0.021	0.048 ^a	0.004	<0.01	NS
6:0	2.64	3.08	2.88	2.94	0.080	NS	NS
7:0	0.031	0.047	0.039	0.085 ^a	0.008	<0.05	NS
8:0	2.95	3.49	3.23	3.08	0.114	NS	NS
4-Methyl octanoate	0.039	0.059	0.039	0.084	0.008	NS	NS
9:0	0.071	0.096	0.082	0.157	0.013	NS	NS
10:0	11.47	11.24	11.03	9.48	0.346	NS	NS
Methyl decanoate	0.060	0.079	0.053	0.105	0.010	NS	NS
12:0	5.64	4.32	4.24 ^a	3.43 ^a	0.266	<0.001	NS
Methyl dodecanoate	0.022	0.029	0.021	0.051	0.005	NS	NS
13:0 <i>iso</i>	0.021	0.020	0.019	0.019	0.003	NS	NS
13:0 <i>anteiso</i>	0.051	0.042	0.030 ^a	0.023 ^a	0.004	<0.01	NS
14:0 <i>iso</i>	0.041	0.056	0.053	0.044	0.003	NS	<0.05
14:0	11.15	9.25 ^a	8.67 ^a	7.66 ^a	0.402	<0.001	NS
Methyl tetradecanoate	0.053	0.057	0.043	0.083	0.007	NS	NS
15:0 <i>iso</i>	0.137	0.129	0.129	0.150	0.005	NS	NS
15:0 <i>anteiso</i>	0.257	0.333	0.247	0.351	0.019	NS	NS
15:0	0.755	0.809	0.658	0.978	0.047	NS	NS
16:0 <i>iso</i>	0.165	0.174	0.150	0.116	0.012	NS	NS
16:0	32.68	24.57 ^a	25.89 ^a	19.96 ^a	1.512	<0.001	NS
17:0	0.393	0.405	0.358	0.433	0.012	NS	NS
18:0 <i>iso</i>	0.046	0.042	0.033	0.034	0.002	<0.05	NS
10-keto 18:0	0.033	0.152	0.346 ^a	0.704 ^a	0.078	<0.001	<0.05
18:0	6.62	9.70	10.64	13.73 ^a	0.913	<0.01	NS
19:0	0.008	0.012	0.011	0.019	0.002	NS	NS
20:0	0.122	0.157 ^a	0.167 ^a	0.175 ^a	0.007	<0.01	NS
21:0	0.029	0.028	0.027	0.036	0.001	NS	NS
22:0	0.060	0.073	0.097 ^a	0.145 ^a	0.010	<0.001	<0.05
MUFA							
<i>c</i> -9-10:1/12:0 <i>iso</i> /11:0	0.313	0.397	0.274	0.281	0.026	NS	NS
<i>c</i> -9-12:1/13:0	0.194	0.177	0.138	0.179	0.012	NS	NS
<i>c</i> -9-14:1	0.179	0.140	0.096 ^a	0.061 ^a	0.016	<0.01	NS
<i>c</i> -9-15:1	0.050	0.060	0.054	0.041	0.004	NS	NS
<i>t</i> -8-16:1	0.047	0.064	0.084	0.127 ^a	0.010	<0.01	NS
<i>t</i> -9-16:1/17:0 <i>iso</i>	0.312	0.331	0.340	0.522 ^a	0.028	<0.01	<0.05
<i>c</i> -7-16:1	0.232	0.274	0.293	0.340	0.017	<0.05	NS
<i>c</i> -8-16:1	0.010	0.013	0.010	0.012	0.001	NS	NS
<i>c</i> -9-16:1/17:0 <i>anteiso</i>	1.14	1.02	0.788 ^a	0.711 ^a	0.057	<0.001	NS
<i>c</i> -13-16:1	0.249	0.177 ^a	0.128 ^a	0.063 ^a	0.022	<0.001	NS
<i>c</i> -9-17:1	0.169	0.174	0.142	0.104	0.009	<0.01	<0.05
<i>t</i> -4-18:1	0.016	0.033	0.047 ^a	0.059 ^a	0.005	<0.01	NS
<i>t</i> -5-18:1	0.016	0.029	0.044 ^a	0.067 ^a	0.006	<0.001	<0.05
<i>t</i> -6/ <i>t</i> -7/ <i>t</i> -8-18:1	0.165	0.332 ^a	0.526 ^a	0.700 ^a	0.062	<0.001	NS
<i>t</i> -9-18:1	0.186	0.295	0.385 ^a	0.434 ^a	0.032	<0.001	NS
<i>t</i> -10-18:1	0.256	0.454	0.770	0.821	0.110	NS	NS
<i>t</i> -11-18:1	0.840	1.22	2.01 ^a	2.66 ^a	0.223	<0.001	NS
<i>t</i> -12-18:1	0.181	0.273	0.425	0.899	0.081	<0.001	<0.001
<i>c</i> -9-18:1	13.63	19.08 ^a	17.80 ^a	19.58 ^a	0.840	<0.01	NS
<i>t</i> -15/ <i>c</i> -11-18:1 ²	0.302	0.338	0.354	0.600 ^a	0.034	<0.001	<0.001
<i>c</i> -12-18:1	0.135	0.115	0.114	0.195	0.011	<0.05	<0.01
<i>c</i> -13-18:1	0.034	0.038	0.043	0.068 ^a	0.005	<0.01	NS
<i>t</i> -16/ <i>c</i> -14-18:1	0.179	0.240	0.239	0.327 ^a	0.017	<0.001	NS
<i>c</i> -15-18:1	0.052	0.058	0.064	0.050	0.003	NS	NS
<i>c</i> -16-18:1	0.020	0.027	0.027	0.026	0.001	NS	NS
<i>c</i> -11-20:1	0.036	0.051	0.056	0.097 ^a	0.007	<0.001	<0.05
Nonconjugated C18:2							
<i>t</i> -11, <i>t</i> -15-18:2	0.048	0.050	0.051	0.056	0.002	NS	NS
<i>t</i> -9, <i>t</i> -12/ <i>c</i> -9, <i>t</i> -13/ <i>t</i> -8, <i>c</i> -12-18:2	0.140	0.188	0.154	0.162	0.011	NS	NS
<i>t</i> -8, <i>c</i> -13-18:2	0.051	0.073 ^a	0.058	0.049	0.004	NS	<0.05
<i>c</i> -9, <i>t</i> -12-18:2 ²	0.022	0.033	0.022	0.033	0.002	NS	NS

Continued

Table 4 (Continued). Experiment 2: milk FA profile (g/100 g of total FA methyl esters) determined by gas chromatography of lactating dairy goats fed none (C), 30 (L), 48 (M), and 66 (H) g/d of high oleic sunflower oil

Item ¹	Treatment				SEM	Effect	
	C	L	M	H		Linear	Quadratic
<i>t</i> -9, <i>c</i> -12-18:2	0.025	0.027	0.030	0.039 ^a	0.002	<0.05	NS
<i>t</i> 11- <i>c</i> 15-18:2	0.030	0.039	0.065 ^a	0.062 ^a	0.006	<0.01	NS
<i>c</i> -9, <i>c</i> -12-18:2 ²	1.72	1.67	1.28	2.20	0.111	NS	<0.05
Other 18:2	0.059	0.069	0.060	0.050	0.003	NS	NS
Conjugated C18:2							
<i>c</i> -9, <i>t</i> -11-18:2	0.487	0.682	0.739	0.799	0.065	NS	NS
<i>t</i> -9, <i>c</i> -11-18:2	0.013	0.017	0.017	0.019	0.001	NS	NS
<i>t</i> -10, <i>c</i> -12-18:2	0.007	0.007	0.010	0.012	0.001	NS	NS
<i>t</i> -11, <i>c</i> -13-18:2	0.012	0.013	0.012	0.013	0.001	NS	NS
<i>t</i> -12, <i>t</i> -14-18:2	0.008	0.008	0.008	0.011	0.001	NS	NS
<i>t</i> -11, <i>t</i> -13-18:2	0.007	0.007	0.007	0.011	0.001	<0.05	NS
<i>t</i> -9, <i>t</i> -11-18:2	0.016	0.016	0.023	0.025	0.002	<0.05	NS
Other PUFA							
16:2	0.008	0.011	0.013	0.013	0.001	NS	NS
18:3n-6	0.019	0.032	0.029	0.010	0.003	NS	<0.05
18:3n-3	0.187	0.165	0.115	0.156	0.011	NS	NS
<i>c</i> -9, <i>t</i> -11, <i>t</i> -15-18:3	0.006	0.006	0.005	0.009	0.001	NS	NS
<i>c</i> -9, <i>t</i> -11, <i>c</i> -15-18:3	0.032	0.040	0.043	0.023	0.003	NS	<0.05
20:2n-6	0.010	0.012	0.010	0.012	0.001	NS	NS
20:3n-3 ²	0.008	0.014	0.007	0.009	0.001	NS	<0.05
20:4n-6	0.124	0.121	0.115	0.100	0.006	NS	NS
20:5n-3	0.030	0.027	0.023	0.031	0.002	NS	NS
22:4n-6	0.023	0.047	0.085	0.157 ^a	0.016	<0.001	NS
22:5n-3	0.048	0.040	0.033	0.040	0.003	NS	NS
22:6n-3	0.016	0.020	0.018	0.010	0.002	NS	NS
ΣSFA	78.07	71.20 ^a	71.52 ^a	66.35 ^a	1.376	<0.001	NS
ΣMUFA	18.75	25.22 ^a	25.12 ^a	28.85 ^a	1.206	<0.001	NS
ΣPUFA	3.18	3.58	3.36	4.80 ^a	0.222	<0.05	NS
Σ <i>t</i> -18:1	2.14	3.21	4.81 ^a	6.57 ^a	0.514	<0.001	<0.05
ΣCLA	0.559	0.751	0.817	0.890	0.068	NS	NS
Atherogenicity index ^{2,3}	3.79	2.30 ^a	2.30 ^a	1.61 ^a	0.255	<0.001	NS
n-6/n-3 PUFA ⁴	5.79	5.99	6.23	8.93 ^a	0.384	<0.001	<0.01
<i>c</i> -9-14:1/14:0 + <i>c</i> -9-14:1	0.016	0.015	0.011	0.008	0.001	<0.05	NS
<i>c</i> -9-18:1/18:0 + <i>c</i> -9-18:1	0.673	0.667	0.627	0.587	0.014	<0.05	NS

^aValues for oil-supplemented diets within rows with the "a" superscript are significantly different from values for the control diet ($P < 0.05$).

¹*c* = *cis*, *t* = *trans*; CLA = conjugated linoleic acid.

²Cubic effect was significant ($P < 0.05$).

³Ulbricht and Southgate (1991): $(12:0 + 4 \times 14:0 + 16:0)/(\text{MUFA} + \text{PUFA})$.

⁴n-6: *c*-9,*c*-12-18:2 + 18:3n-6 + 20:2n-6 + 20:4n-6 + 22:4n-6; n-3: 18:3n-3 + *c*-9,*t*-11,*t*-15-18:3 + *c*-9,*t*-11,*c*-15-18:3 + 20:3n-3 + 20:5n-3 + 22:5n-3 + 22:6n-3.

RESULTS

Oleic and linoleic acids were the predominant FA in the HOSFO and RSFO diets, respectively, whereas LO diets showed a more balanced supply of the 3 main FA of plant origin: oleic, linoleic and α -linolenic, although the last one was quantitatively the most important (Table 1). Adding oil did not affect intake, milk yield, and fat, protein and lactose contents (Table 2). It can be calculated from intake figures in Table 2 that actual oil intake was close to the aimed targets: 28.1, 44.6, and 61.1 g/d; 29.3, 46.5, and 63.3 g/d; and 28.3, 44.9, and 61.1 g/d for the L, M, and H diets in the LO, HOSFO, and RSFO experiments, respectively.

Tables 3, 4, and 5 show the milk FA profile in the experiments, which included LO, HOSFO, and RSFO,

respectively. Table 6 shows Pearson correlation coefficients between daily intake of plant oils and the content of selected FA in milk fat. About 80 different peaks were identified and quantified by GC. Of these FA, 25 did not show any significant linear effect and 58 did not have quadratic effect, whatever the experiment or the treatment was. No cubic effects were found in the LO experiment and only 2 and 5 cubic effects were found in the RSFO and HOSFO experiments, respectively.

Nine milk fat FA showed common linear effects of oil supplementation, whatever the oil was. The content of 14:0 and especially 16:0 in milk fat was negatively affected by the oil supplementation. The effect was greater the higher the level of oil inclusion in all the experimental treatments. On the other hand, lauric acid decreased and stearic acid increased in a linear man-

Table 5. Experiment 3: milk FA profile (g/100 g of total FA methyl esters) determined by gas chromatography of lactating dairy goats fed none (C), 30 (L), 48 (M), and 66 (H) g/d of regular sunflower oil

Item ¹	Treatment				SEM	Effect	
	C	L	M	H		Linear	Quadratic
SFA							
4:0	2.60	2.85	2.58	2.74	0.107	NS	NS
5:0	0.029	0.021	0.018	0.025	0.003	NS	NS
6:0	2.95	2.52	2.95	2.90	0.080	NS	NS
7:0	0.051	0.030	0.033	0.048	0.005	NS	NS
8:0	3.36	2.36	3.29	3.12	0.192	NS	NS
4-Methyl octanoate	0.066	0.020	0.036	0.054	0.008	NS	NS
9:0	0.105	0.051	0.066	0.087	0.010	NS	NS
10:0	12.39	8.35	11.22	9.60	0.790	NS	NS
Methyl decanoate	0.102	0.032	0.049	0.072	0.012	NS	NS
12:0	5.65	4.30	4.19	3.77	0.279	<0.05	NS
Methyl dodecanoate	0.035	0.012	0.017	0.031	0.004	NS	<0.05
13:0 <i>iso</i>	0.013	0.022	0.017	0.019	0.002	NS	NS
13:0 <i>anteiso</i>	0.062	0.056	0.030	0.033	0.006	<0.05	NS
14:0 <i>iso</i>	0.054	0.057	0.048	0.042	0.006	NS	NS
14:0	10.80	9.66	8.28 ^a	8.01 ^a	0.386	<0.01	NS
Methyl tetradecanoate	0.087	0.031	0.038	0.049	0.008	NS	<0.05
15:0 <i>iso</i>	0.133	0.167	0.101	0.127	0.011	NS	NS
15:0 <i>anteiso</i>	0.305	0.318	0.230	0.300	0.028	NS	NS
15:0	0.951	0.789	0.589	0.727	0.062	NS	NS
16:0 <i>iso</i>	0.205	0.137	0.113	0.150	0.014	NS	NS
16:0	31.97	29.82	25.54 ^a	20.89 ^a	1.442	<0.01	NS
17:0	0.436	0.397	0.309	0.366	0.030	NS	NS
18:0 <i>iso</i>	0.044	0.038	0.037	0.049	0.004	NS	NS
10-keto18:0	0.031	0.071	0.287	0.172	0.052	NS	NS
18:0	5.46	9.00	10.37 ^a	10.45 ^a	0.747	<0.05	NS
19:0	0.010	0.011	0.014	0.017	0.001	NS	NS
20:0	0.113	0.119	0.146	0.154	0.007	<0.05	NS
21:0	0.029	0.025	0.023	0.025	0.001	NS	NS
22:0	0.049	0.098	0.075	0.092	0.010	NS	NS
MUFA							
<i>c</i> -9-10:1/12:0 <i>iso</i> /11:0	0.464	0.298 ^a	0.276 ^a	0.277 ^a	0.027	<0.01	NS
<i>c</i> -9-12:1/13:0	0.256	0.176	0.138	0.152	0.018	<0.05	NS
<i>c</i> -9-14:1	0.185	0.246	0.096	0.107	0.031	NS	NS
<i>c</i> -9-15:1	0.054	0.045	0.056	0.058	0.003	NS	NS
<i>t</i> -8-16:1	0.052	0.061	0.056	0.130	0.014	NS	NS
<i>t</i> -9-16:1/17:0 <i>iso</i> ²	0.340	0.431	0.320	0.662 ^a	0.051	<0.05	NS
<i>c</i> -7-16:1	0.213	0.228	0.289	0.292	0.017	NS	NS
<i>c</i> -8-16:1	0.013	0.012	0.013	0.017	0.001	NS	NS
<i>c</i> -9-16:1/17:0 <i>anteiso</i>	1.20	1.29	0.795	0.774	0.101	NS	NS
<i>c</i> -13-16:1	0.282	0.173	0.135 ^a	0.094 ^a	0.024	<0.01	NS
<i>c</i> -9-17:1	0.183	0.159	0.132	0.117	0.010	<0.05	NS
<i>t</i> -4-18:1 ²	0.014	0.021	0.042 ^a	0.036 ^a	0.004	<0.01	NS
<i>t</i> -5-18:1	0.019	0.017	0.038	0.036	0.004	<0.05	NS
<i>t</i> -6/ <i>t</i> -7/ <i>t</i> -8-18:1	0.143	0.279	0.424	0.515 ^a	0.050	<0.01	NS
<i>t</i> -9-18:1	0.162	0.286	0.357 ^a	0.488 ^a	0.040	<0.01	NS
<i>t</i> -10-18:1	0.295	0.418	0.929	2.55 ^a	0.345	<0.05	NS
<i>t</i> -11-18:1	0.693	2.10	2.28	5.09 ^a	0.564	<0.01	NS
<i>t</i> -12-18:1	0.180	0.294	0.337	0.434	0.035	<0.05	NS
<i>c</i> -9-18:1	12.88	17.09	18.15	16.49	0.847	<0.05	NS
<i>t</i> -15/ <i>c</i> -11-18:1	0.280	0.416	0.363	0.507	0.046	NS	NS
<i>c</i> -12-18:1	0.185	0.191	0.125	0.586	0.088	NS	NS
<i>c</i> -13-18:1	0.032	0.049	0.057	0.055	0.004	NS	NS
<i>t</i> -16/ <i>c</i> -14-18:1	0.176	0.281	0.299 ^a	0.362 ^a	0.022	<0.01	NS
<i>c</i> -15-18:1	0.060	0.069	0.068	0.073	0.004	NS	NS
<i>c</i> -16-18:1	0.023	0.035	0.032	0.041	0.005	NS	NS
<i>c</i> -11-20:1	0.047	0.042	0.052	0.050	0.003	NS	NS
Nonconjugated C18:2							
<i>t</i> -11, <i>t</i> -15-18:2	0.037	0.035	0.038	0.030	0.002	NS	NS
<i>t</i> -9, <i>t</i> -12/ <i>c</i> -9, <i>t</i> -13/ <i>t</i> -8, <i>c</i> -12-18:2	0.167	0.213	0.192	0.243	0.013	NS	NS
<i>t</i> -8, <i>c</i> -13-18:2	0.056	0.073	0.082	0.063	0.006	NS	NS
<i>c</i> -9, <i>t</i> -12-18:2	0.027	0.039	0.032	0.024	0.004	NS	NS

Continued

Table 5 (Continued). Experiment 3: milk FA profile (g/100 g of total FA methyl esters) determined by gas chromatography of lactating dairy goats fed none (C), 30 (L), 48 (M), and 66 (H) g/d of regular sunflower oil

Item ¹	Treatment				SEM	Effect	
	C	L	M	H		Linear	Quadratic
<i>t</i> -9, <i>c</i> -12-18:2	0.032	0.033	0.041	0.049	0.004	NS	NS
<i>t</i> -11, <i>c</i> -15-18:2	0.039	0.061	0.065	0.066	0.009	NS	NS
<i>c</i> -9, <i>c</i> -12-18:2	2.04	1.73	1.47	2.89	0.245	NS	NS
Other 18:2	0.050	0.057	0.043	0.046	0.004	NS	NS
Conjugated C18:2							
<i>c</i> -9, <i>t</i> -11-18:2	0.410	1.03	0.894	1.86 ^a	0.209	<0.05	NS
<i>t</i> -9, <i>c</i> -11-18:2	0.012	0.015	0.022	0.036	0.004	<0.05	NS
<i>t</i> -10, <i>c</i> -12-18:2	0.009	0.008	0.009	0.011	0.001	NS	NS
<i>t</i> -11, <i>c</i> -13-18:2	0.012	0.015	0.013	0.010	0.001	NS	NS
<i>t</i> -12, <i>t</i> -14-18:2	0.007	0.013	0.011	0.008	0.002	NS	NS
<i>t</i> -11, <i>t</i> -13-18:2	0.006	0.008	0.009	0.006	0.001	NS	NS
<i>t</i> -9, <i>t</i> -11-18:2	0.015	0.022	0.018	0.022	0.002	NS	NS
Other PUFA							
16:2	0.005	0.009	0.011	0.013	0.001	<0.05	NS
18:3n-6	0.033	0.021	0.024	0.026	0.002	NS	NS
18:3n-3	0.208	0.229	0.121	0.131	0.028	NS	NS
<i>c</i> -9, <i>t</i> -11, <i>t</i> -15-18:3	0.006	0.007	0.009	0.022	0.004	NS	NS
<i>c</i> -9, <i>t</i> -11, <i>c</i> -15-18:3	0.030	0.030	0.041	0.032	0.003	NS	NS
20:2n-6	0.012	0.014	0.013	0.013	0.001	NS	NS
20:3n-3	0.009	0.006	0.007	0.006	0.001	NS	NS
20:4n-6	0.127	0.128	0.113	0.116	0.004	NS	NS
20:5n-3	0.033	0.026	0.026	0.019	0.002	NS	NS
22:4n-6	0.025	0.031	0.082	0.049	0.011	NS	NS
22:5n-3	0.050	0.047	0.034	0.038	0.004	NS	NS
22:6n-3	0.017	0.017	0.022	0.015	0.002	NS	NS
ΣSFA	78.33	71.49 ^a	70.55 ^a	64.16 ^a	1.573	<0.001	NS
ΣMUFA	18.18	24.53 ^a	25.73 ^a	29.85 ^a	1.311	<0.001	NS
ΣPUFA	3.50	3.98	3.72	5.99 ^a	0.376	<0.01	NS
Σ <i>t</i> -18:1	1.96	4.11	5.07	10.02 ^a	1.026	<0.01	NS
ΣCLA	0.471	1.11	0.976	1.95 ^a	0.213	<0.01	NS
Atherogenicity index ³	3.75	2.56 ^a	2.14 ^a	1.60 ^a	0.239	<0.001	NS
n-6/n-3 PUFA ⁴	6.30	5.90	6.70	11.46 ^a	0.849	<0.05	<0.05
<i>c</i> -9-14:1/14:0 + <i>c</i> -9-14:1	0.017	0.018	0.011	0.013	0.001	NS	NS
<i>c</i> -9-18:1/18:0 + <i>c</i> -9-18:1	0.701	0.657	0.637	0.613	0.015	NS	NS

^aValues for oil-supplemented diets within rows with the "a" superscript are significantly different from values for the control diet ($P < 0.05$).

¹*c* = *cis*, *t* = *trans*; CLA = conjugated linoleic acid.

²Cubic effect was significant ($P < 0.05$).

³Ulbricht and Southgate (1991): $(12:0 + 4 \times 14:0 + 16:0)/(\text{MUFA} + \text{PUFA})$.

⁴n-6: *c*-9,*c*-12-18:2 + 18:3n-6 + 20:2n-6 + 20:4n-6 + 22:4n-6; n-3: 18:3n-3 + *c*-9,*t*-11,*t*-15-18:3 + *c*-9,*t*-11,*c*-15-18:3 + 20:3n-3 + 20:5n-3 + 22:5n-3 + 22:6n-3.

ner with the increasing oil addition in the RSFO and HOSFO experiments, but not in the LO experiment.

Oleic acid showed a linear effect of increasing additions of HOSFO but not of RSFO or LO supplementations. Other MUFA also demonstrated linear effects of the supplementation of some but not all the oils (Tables 3, 4, and 5). Vaccenic acid showed a linear increase in all the 3 experiments but this was numerically lower in experiment with HOSFO than in experiments with RSFO and LO. The content of *t*-10-18:1 was not affected by increasing levels of LO; however, an increasing linear trend was observed with HOSFO and a significant linear effect with RSFO. The lowest levels of *t*-10-18:1 were measured in LO diets. On the other hand, *t*-15-18:1 (co-eluted with *c*-11-18:1) showed an increasing response to HOSFO diets and LO diets. The latter produced a positive linear effect in milk fat con-

tent of *c*-15-18:1, which did not appear in milk fat of goats fed HOSFO and RSFO diets.

The CLA isomers did not show a common response to all the 3 oils used in the 3 experiments. Two isomers (*t*-11,*c*-13-18:2 and *t*-12,*t*-14-18:2) showed a positive linear effect only with LO diets. Rumenic acid showed a positive linear effect with LO and RSFO diets. Two other FA, *t*-11,*t*-13-18:2 and *t*-9,*t*-11-18:2, responded positively to the LO and HOSFO diets, and one (*t*-9,*c*-11-18:2) to the RSFO diets but not to the HOSFO and LO diets. Finally, 18:3n-3, *c*-9,*t*-11,*t*-15-18:3, *c*-9,*t*-11,*c*-15-18:3, and 20:5n-3 showed positive linear effects only with the LO diets (Table 3).

By classes, the sum of SFA had a common negative linear response to dietary oil inclusion, whereas the sums of MUFA and PUFA responded positively to all of the oil-supplemented diets. The sum of *t*-18:1

Table 6. Significant ($P < 0.05$) Pearson correlation coefficients between the intake of plant oils (g/d) and the content of selected FA in goat milk (g/100 g of total FA methyl esters)

FA ¹	Oil		
	Linseed	High oleic sunflower	Regular sunflower
4:0 + 6:0 + 8:0 + 10:0	NS	NS	NS
12:0 + 14:0 + 16:0	-0.89	-0.91	-0.94
18:0	NS	0.82	0.73
<i>t</i> -10-18:1	NS	0.64	0.71
<i>t</i> -11-18:1	0.92	0.91	0.79
<i>c</i> -9-18:1	NS	0.75	NS
<i>t</i> -15/ <i>c</i> -11-18:1	0.90	0.76	NS
<i>c</i> -15-18:1	0.94	NS	NS
<i>t</i> -11, <i>t</i> -15-18:2	0.74	NS	NS
<i>t</i> -11, <i>c</i> -15-18:2	0.89	0.78	NS
<i>c</i> -9, <i>c</i> -12-18:2	NS	NS	NS
<i>c</i> -9, <i>t</i> -11-18:2	0.83	NS	0.67
<i>t</i> -9, <i>c</i> -11-18:2	NS	0.63	0.68
<i>t</i> -10, <i>c</i> -12-18:2	NS	NS	NS
<i>t</i> -11, <i>c</i> -13-18:2	0.81	NS	NS
<i>t</i> -12, <i>t</i> -14-18:2	0.68	NS	NS
<i>t</i> -11, <i>t</i> -13-18:2	0.83	NS	NS
<i>t</i> -9, <i>t</i> -11-18:2	0.82	0.70	NS
18:3n-3	0.82	NS	NS
<i>c</i> -9, <i>t</i> -11, <i>t</i> -15-18:3	0.92	NS	NS
<i>c</i> -9, <i>t</i> -11, <i>c</i> -15-18:3	0.71	NS	NS
ΣCLA	0.84	NS	0.67

¹*t* = *trans*; *c* = *cis*; CLA = conjugated linoleic acid.

FA increased linearly with oil supplementation in all of the experiments. In contrast, the sum of CLA isomers showed a positive linear response to LO and RSFO but not to HOSFO supplementation.

The atherogenicity index had a common decreasing response to oil supplementation. In the LO experiment, the addition of any amount of linseed oil to the basal diet (low in α -linolenic acid; Table 1) produced a sharp decrease in the n-6/n-3 PUFA ratio. On the contrary, the major increase in this ratio was observed in the RSFO diet with the highest level of added oil (Table 5). The n-6/n-3 PUFA ratio in milk fat decreased by about 70% (from 6.03 to 1.85) with the highest level of LO supplementation (Table 3), whereas the most remarkable increase (from 6.30 to 11.46) was observed with diet H of the RSFO treatment (Table 5).

DISCUSSION

When feeding diets supplemented with plant oils to dairy goats, normally no appreciable differences in milk production and protein content are obtained, but usually some increases in fat content are produced (Chilliard et al., 2003, 2007). No differences were found in milk yield and fat, protein, and lactose content in this work, which was not designed to find such differences (due to the low number of goats used per group, high individual variations in fat content, and the lack of use of pre-experimental covariates) but to find out differences in the milk fat FA profile.

A large number of reports carried out in dairy ruminants show that adding fat sources rich in UFA to diets decreases the content of short- and medium-chain SFA in milk fat. According to Chilliard and Ferlay (2004), the reason for this response may have a double origin. First, a decreased production of VFA in the rumen due to dietary UFA would decrease the amount of substrate for FA synthesis in the mammary cell. Second, the long-chain FA taken up by the mammary gland could inhibit enzymatic activities in the pathways of FA synthesis in the mammary cell. In this work, it appears that no shortage of substrate existed for the synthesis of short- and medium-chain SFA in the mammary gland of goats eating the oil-supplemented diets because most odd- and branched-chain FA did not show variation with the addition of increasing amount of oils to the control diet (Tables 3, 4, and 5), which can be considered as an index of lack of severe negative effects of the added oils on the rumen microbial activity (Harfoot and Hazlewood, 1997; Vlaeminck et al., 2006). In contrast, Bernard et al. (2009c) observed negative effects of added oils (RSFO and LO) on odd and branched FA content in milk fat. This could be only partly attributed to the dose of added oil (130 g/d). In comparison, in the current research, the intake of oil with the highest level of added oil was slightly lower (0.70 or 0.98 on a DMI or milk fat yield basis, respectively) than that reported by Bernard et al. (2009c).

Recently, Bernard et al. (2009a) considered that the inhibition of major lipogenic genes or enzymes may not

Figure 1. *Trans*-10-18:1, *trans*-11-18:1, and *cis*-9,*trans*-11-18:2 contents and n-6/n-3 ratio in milk fat of goats fed none, 30, 48, and 66 g/d of linseed oil (LO), high oleic sunflower oil (HOSFO), or regular sunflower oil (RSFO). FAME = FA methyl esters.

be the main cause (other than decreased substrate) of the negative response of short- and medium-chain SFA to plant oils and that other metabolic pathways or genes can be involved. The cause of the significant decrease observed in the milk fat concentration of 12:0, except with LO, 14:0, and 16:0, and its negative correlation to daily oil intake (Table 6) in all 3 experiments of this work, could be the inhibiting effect of the increasing supply of long-chain FA to the mammary gland on the ratio of acetyl-CoA carboxylase to FA synthetase activities. Results of in vitro research cited by Bauman and Davis (1974) show that altering the ratio of acetyl-CoA carboxylase to FA synthetase activities in the mammary cell shifts the pattern of FA synthesized toward the shorter chain types when the ratio decreases. The same effect is obtained when the ratio of acetyl-CoA to malonyl-CoA increases. Results obtained by Bernard et al. (2009a) point in that direction: the ratio of acetyl-CoA carboxylase to FA synthetase activities decreased in their work by 32 and 40% without reduction of the secretion (and content) of FA from 4:0 to 8:0 in goat milk fat when diets including RSFO

or LO, respectively, were fed instead of a control diet. That could also be the case in the current work, as the shorter FA (4:0 to 8:0) showed no negative, even positive, responses to oil supplementation (Tables 3, 4, and 5). Capric acid was in an intermediate position as was not significantly affected but, at least in the HOSFO experiment, showed a negative linear trend. The sum of 4:0 to 10:0 content in milk fat was uncorrelated to daily oil intake (Table 6).

The fact that in this work the milk fat content of 4:0, 6:0, and 8:0 was not decreased by dietary oil supplementation, and that the generally observed negative effects on short- and medium-chain SFA started clearly only from 12:0 upwards, except with LO, is a frequent observation in goat experiments (Okine et al., 2003; Nudda et al., 2006; Bouattour et al., 2008). However in other studies (Bernard et al., 2005, 2009c; Ollier et al., 2009) a decrease in milk 10:0, and even 8:0 (and less frequently 6:0) has also been documented.

In this work, most 18:0 in milk fat would come from a complete rumen biohydrogenation (BH) of dietary UFA because 18:0 ingested with the control and oil-

supplemented diets (Table 1) was much lower than 18:0 yield in milk fat (calculated from Table 2 and Tables 3, 4, and 5). Any 18-carbon UFA in the rumen may be the source of 18:0 through BH. As a result, a significant linear effect on 18:0 content was observed in the HOSFO and RSFO diets. In contrast, the lack of linear effect of LO diets would indicate that they did not favor a complete rumen BH of the UFA, raising the contents of α -linolenic acid and its intermediates in milk fat. With diets based on grass hay and concentrates, Bernard et al. (2009c) did not find differences of 18:0 content in milk fat between LO- and sunflower oil-added diets, although they did find such differences with diets based on maize silage and concentrates.

The *c*-9-18:1 in milk fat may have a double origin. It may come from preformed *c*-9-18:1 taken up by the mammary gland or it may be formed in the udder by Δ^9 desaturation of 18:0. Enjalbert et al. (1998) observed in cows that desaturation of 18:0 in the mammary gland to *c*-9-18:1 averaged about half of the uptake. In the HOSFO experiment, the milk fat content of *c*-9-18:1 with the L diet increased when compared with that of the C diet to a level not different than that showed by the greater HOSFO intakes with the M and H diets. It seemed logical to find higher contents of oleic acid in milk fat of goats fed greater amounts of oleic acid. However, oleic acid is preferably converted into a wide variety of *t*-MUFA (Mosley et al., 2002; Gómez-Cortés et al., 2008b). Furthermore, an inhibition of the stearoyl-CoA desaturase (SCD) by the increased availability of PUFA and *t*-FA in the mammary gland was suggested by Chilliard and Ferlay (2004). In goats, Bernard et al. (2005) reported lower values of SCD activity when supplementing a control diet with 3.6% of HOSFO. In our study, the ratio of *c*-9-18:1 to 18:0 plus *c*-9-18:1, decreased as the supplementation of HOSFO increased (Table 4), which suggests that desaturation in the HOSFO experiment did not keep pace with the increased supply of stearic acid to the udder. The linear decrease in the ratio *c*-9-14:1 to 14:0 plus *c*-9-14:1 would support this contention (Table 4). No changes in the ratio *c*-9-14:1 to 14:0 plus *c*-9-14:1 were observed in the RSFO or LO experiments, although the ratio *c*-9-18:1 to 18:0 plus *c*-9-18:1 tended to decrease in the RSFO experiment (Tables 3 and 5). Moreover, the daily intake of LO was correlated neither with the content of 18:0 nor with *c*-9-18:1 in milk fat (Table 6). The lack of response of *c*-9-18:1 in milk fat to LO supplementation is consistent with dairy goat data of Chilliard et al. (2003, 2007) and Chilliard and Ferlay (2004), although some published research shows positive responses of *c*-9-18:1 to linseeds or linseed oil supplementation (Bernard et al., 2005, 2009a; Nudda et al., 2006), but not that of Nudda et al. (2007) who reported no increases in *c*-9-

18:1 content in milk fat when supplementing diets with extruded linseed cake.

The clear positive response of most of the *t*-MUFA to all the different supplements could be interpreted as an incomplete BH of dietary UFA in the rumen, leaving many MUFA and PUFA intermediates along the BH pathways. The content of VA in milk fat increased faster with oil supplementation in the RSFO and LO experiments than in the HOSFO experiment, the values obtained with the H diets of those 2 experiments being twice as high as that observed with the H diet in the HOSFO experiment (Figure 1). Vaccenic acid is the main intermediate product in the BH pathways of 18:2 and 18:3n-3 (Bauman et al., 1999). In contrast, VA is not the predominant BH product of *c*-9-18:1 and, as a result of its isomerization, a wide spectrum of *t*-MUFA are obtained (Mosley et al., 2002; AbuGhazaleh et al., 2005; Gómez-Cortés et al., 2008b). In the present work, the VA content in milk fat was in accordance with the last 2 statements, as the VA content in milk fat with the RSFO and LO diets was much higher than with the HOSFO diets.

The isomer *t*-10-18:1 increased more with the H diet in the RSFO experiment than in the corresponding diet of the HOSFO experiment (Figure 1). Gómez-Cortés et al. (2008a,b) reported a similar pattern (i.e., higher content of *t*-10-18:1 in milk fat of ewes fed a linoleic acid-rich diet instead of an oleic acid-rich one). In contrast, Bodas et al. (2010) found similar contents of *t*-10-18:1 when feeding dairy ewes diets rich in oleic or linoleic acids, probably due to their basal diet having a high forage:concentrate ratio. It is well known that rations rich in concentrate favor the shift in the 18:2 rumen BH pathways toward the formation of higher levels of *t*-10-18:1 in milk fat (Shingfield and Griinari, 2007). On the other hand, the BH of 18:3n-3 is less prone to promote *t*-10-18:1 formation than that of linoleic acid (AbuGhazaleh and Jacobson, 2007) and consistent with this, the content of *t*-10-18:1 did not increase in LO-fed goats, which would be positive from a nutritional point of view. Larger increases in *t*-10-18:1 milk fat content in response to RSFO in comparison with LO supplementation were also reported by Bernard et al. (2009c) using diets similar in starch and NDF content to those assayed in the present trial.

Total CLA isomers were positively correlated with daily LO and RSFO intake but not with HOSFO intake (Table 6). This is not unexpected, as *c*-9-18:1 was the main FA supplied by HOSFO, and oleic acid is not converted to CLA isomers during rumen BH. Of the 5 CLA isomers responding to LO in this work, only RA had a positive response to RSFO. A similar result was also reported by Bernard et al. (2009c) who used a daily amount of supplemental oil higher than the high-

est level assayed in the present work. Rumenic acid, which mainly originates in the udder by desaturation of VA (Bauman et al., 1999; Bernard et al., 2010), increased in the milk fat of goats fed LO and RSFO diets to levels slightly higher than the (nonsignificant) responses obtained with HOSFO diets (Figure 1).

In the LO experiment, an increase in the BH intermediates of 18:3n-3 was observed in milk from goats fed the supplemented diets. The group *c*-9,*t*-11,*c*-15-18:3; *t*-11,*c*-15-18:2; and *c*-15-18:1 belongs to a well-known BH pathway (Harfoot and Hazlewood, 1997); the group *c*-9,*t*-11,*t*-15-18:3; *t*-11,*t*-15-18:2; and *t*-15-18:1 corresponds to an alternative pathway recently postulated by Gómez-Cortés et al. (2009), working with dairy ewes, and the CLA isomer *t*-11,*c*-13-18:2 was postulated from a dairy cow study by Kraft et al. (2003) and Collomb et al. (2004) as a probable intermediate of an unknown BH pathway of 18:3n-3. Luna et al. (2008) and Bernard et al. (2009c) found the isomer *t*-15-18:1 and the isomer *t*-11,*t*-15-18:2, respectively, in milk fat of LO-fed goats. The CLA isomer *t*-11,*c*-13-18:2 was reported by Luna et al. (2008) and Bernard et al. (2009a,c) in milk of goats fed whole linseed and LO, respectively. All of these isomers involved in the BH of 18:3n-3 showed positive correlations with the daily intake of LO (Table 6).

As a consequence of the negative linear effect of oil addition on the content of 12:0, 14:0, and 16:0, and the increased content of UFA in milk fat, the atherogenicity index decreased in the milk of all 3 experiments (Tables 3, 4, and 5). This was also observed in dairy ewes by Bodas et al. (2010). The decreased ratio of n-6 to n-3 PUFA in milk fat from goats fed LO-supplemented diets (Figure 1) was expected, as LO was the only oil used in this work with significant content of 18:3n-3. This effect is commonly reported when LO or linseeds are included in the diet of cows, goats, and ewes (Bu et al., 2007; Chilliard et al., 2007; Bodas et al., 2010). The observed increase of n-6 to n-3 PUFA in milk fat from goats fed RSFO-supplemented diets agrees with the results reported from research conducted with ewes by Bodas et al. (2010) who also observed a larger increase in n-6 to n-3 PUFA in milk fat when the supplemented oil was richer in 18:2 (sunflower oil) than in *c*-9-18:1 (olive oil).

CONCLUSIONS

An effect observed in this work was that the responses in the proportions of milk fat FA to dietary increases of the 3 oils tested, when present, were linear for several FA. Considering that the consumption of RA is beneficial for human health and that VA is a source of RA, adding LO and RSFO to goat diets seems

favorable because it resulted in milk richer in both FA. In contrast, supplementation with HOSFO did not significantly modify milk RA, whereas VA increased only by about half of the increases obtained with the other 2 oils. On the other hand, the content of *t*-10-18:1, whose intake could be considered a risk factor for cardiovascular disease in humans, did not increase in milk fat with increasing LO dietary supplementation. Besides that, the decreased ratio of n-6 to n-3 FA in milk fat from diets supplemented with LO also contributes to make this oil, especially at the highest level, the most favorable alternative compared with HOSFO or RSFO.

ACKNOWLEDGMENTS

This work was financed by the Ministerio de Ciencia e Innovación (MICINN; AGL2008-04805 and Consolider Ingenio 2010 Programme; FUN-C-FOOD CSD2007-063) and the Comunidad Autónoma de Madrid (Spain; 2009-AGR-1469). The authors thank A. Jiménez Secilla and B. Garfia Catalán of Laboratorio Agropecuario Regional of Córdoba (Spain) for their help with milk composition analysis, I. Andújar-Ramírez (University of Córdoba, Spain) and M. V. Rodríguez-Pino (CSIC, Madrid, Spain) for their technical assistance in processing milk samples, and J. J. Pérez-Hernández (University of Córdoba, Spain) for his assistance in the animal feeding and management.

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