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Fatty acid composition of muscle and adipose tissues of indigenous Caribbean goats under varying nutritional densities¹

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ABSTRACT: The effects of a concentrate diet on growth, carcass fat, and fatty acid (FA) composition of muscle (supraspinatus), perirenal, and intermuscular adipose tissues of Creole goats ($n = 32$) were evaluated. Goats were fed a tropical green forage *Digitaria decumbens* ad libitum with no concentrate (G0) or 1 of 3 levels of concentrate: 140 (G100), 240 (G200), and 340 g·d⁻¹ (G300), respectively. Goats were slaughtered according to the standard procedure at the commercial BW (22 to 24 kg of BW). Goats fed the concentrate diets (G100, G200, and G300) had greater ADG ($P < 0.001$), cold carcass weights ($P < 0.001$), and omental ($P < 0.01$), perirenal ($P < 0.01$), and intermuscular ($P < 0.01$) adipose tissues weights. Dietary intake of C18:0, C18:1n-9, C18:2n-6 increased as concen-

trate supplementation increased ($P < 0.001$), whereas C18:3n-3 intake was not affected ($P > 0.05$). Increased concentrate supplementation did not affect ($P > 0.05$) the proportion of MUFA in all tissues and had very little effect on SFA in perirenal tissue, but increased the PUFA proportion in muscle ($P < 0.05$). The major effect of feeding increased concentrate was an increase in n-6 PUFA proportions in all tissues ($P < 0.001$) and, surprisingly, a decrease in n-3 PUFA ($P < 0.001$). Focusing on FA, which are supposed to have a beneficial or an adverse effect on human health, feeding increased concentrate did not increase the content of any cholesterol-increasing SFA in meat, but increased the n-6/n-3 ratio above 4 when more than 240 g of concentrate was fed per day.

Key words: adipose tissue, concentrate, fatty acid, goat, muscle, tropical forage

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INTRODUCTION

The consumption of fat in meat from ruminants has been associated with high-calorie intakes and fatty acid

(FA) profiles that are associated with health problems. To overcome this problem, ruminant meat producers need to focus on producing a leaner meat with decreased proportions of SFA, especially C14:0 and C16:0, and increased proportions of *cis*-MUFA and PUFA, especially long-chain PUFA of the n-3 series. The potential health benefits would be improved if *trans*-MUFA were reduced and CLA were increased, especially the C18:2*cis*-9, *trans*-11 isomer (Aurousseau et al., 2004). In this context, goat meat has an advantage over beef and lamb due to its low fat content (Webb and O'Neill, 2008) and a favorable FA composition of fat (Banskaliéva et al., 2000).

Supplementing forage-feeding (FF) with concentrates (CF) improved ADG of kids but also increased carcass fat content because of greater energy intakes (Ryan et al., 2007). It has been speculated that concentrate feeding might be associated with changes in the FA profile of muscle and fat due to the differences in the FA content and profile of feed ingredients. Meat from forage-fed ruminants has a greater n-3 PUFA content than that from concentrate-fed-ruminants, despite increased ruminal PUFA biohydrogenation in these

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²The first author is the PhD student who was in charge of all field and laboratory measures, the constitution of the experimental database, and the literature review.

³These authors contributed equally to this study: G. Alexandre in the design of the experiment, growth and feeding measurements, and V. Berthelot in fatty acid determination and manuscript redaction. The 3 authors contributed equally to the data processing and to enriching the discussion.

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Table 1. Ingredients, chemical composition, and fatty acid (FA) content of the different components of the diets

Item	Tropical forage	Commercial pellet ¹
DM, ² %	23.3	88.9
Chemical composition, ² g·kg ⁻¹ of DM		
CP	108	209
Ether extract	14	25
NDF	686	168
ADF	328	47
FA	4.2	14.2
C16:0, % of FA	36.0	32.0
C18:0, % of FA	6.0	4.6
C18:1n-9, % of FA	6.7	36.3
C18:2n-2, % of FA	21.2	24.7
C18:3n-3, % of FA	26.7	1.0

¹Composition, per kilogram as-fed basis: 680 g of corn grain, 150 g of soybean cake, 110 g of wheat bran, 10 g of urea, and 50 g of vitamin and mineral supplement.

²Nutrient composition based on laboratory analyses.

animals, due to the greater C18:3 content in forage compared with most concentrates (Ryan et al., 2007; Webb and O'Neill, 2008). However, the beneficial effect of a FF system on FA composition is not always clear; Rhee et al. (2000) observed that the intramuscular fat of range goats had more SFA than intramuscular fat from goats fed a grain diet.

Because local demand for Creole goat meat is high in the Caribbean area, different feeding systems were studied to improve its meat production. The growth performance, carcass quality, and noncarcass components of the indigenous Caribbean goats in these feeding systems have been reported in a companion paper (Liméa et al., 2009a). The present study examined the effect of these FF and CF systems on the FA composition of adipose tissues and muscle in Creole kids.

MATERIALS AND METHODS

The study was conducted on the Experimental Farm of the Institut National de Recherche Agronomique (INRA) Animal Production Research Unit in Guadeloupe and is fully described in Liméa et al. (2009a). All animal care, handling techniques, and slaughter procedures were approved by the INRA Animal Care and Use Committee before the research was initiated.

Experimental Diets and Animals

Thirty-two male indigenous Caribbean goats (9.0 ± 0.2 kg at 3 mo old) from a total of 40 (Liméa et al., 2009a) were reared in individual pens. Kids were blocked by BW and ADG between 30 and 70 d pre-weaning and were randomly assigned to 1 of the 4 groups. Each group (8 replicates per group) received a different diet with a different level of concentrate supplementation. The first group (**G0**) was fed ad libitum a basal diet exclusively made up of *Digitaria decumbens*, a green tropical forage, that was cut daily at 28 d of regrowth. The animals in the other 3 groups (**G100**,

G200, and **G300**) received daily the same basal diet plus 140, 240, or 340 g (as fed) of a commercial concentrate, respectively. The concentrate was made up of maize (68%), soybean cake (15%), and wheat bran (11%). The chemical and FA composition of forage and concentrate are presented in Table 1.

Slaughtering Procedure

Animals were slaughtered at a fixed BW of 22 to 24 kg. They were weighed and fasted the day before slaughter. The slaughtering procedures followed the methods standardized by Colomer-Rocher et al. (1987). The omental fat (**OF**) was removed and weighed. Dressed carcasses were weighed within 1 h of slaughter (HCW) and after chilling for 24 h at 4°C (cold carcass weight). The perirenal fat (**PR**) was removed, weighed, sampled, and frozen at -30°C. The left shoulder was separated from the cold carcass for dissection and analysis (see Liméa et al., 2009a), and samples of muscle (supraspinatus, **SS**) and intermuscular adipose (**IM**) tissues were removed and frozen at -30°C until chemical analysis was done.

Chemical Analysis

Samples of forage (2 subsamples of 200 g) were taken each day from Monday to Friday. One of the subsamples was kept for daily DM determination. All the samples of the feed collected during 2 wk were mixed together for each kid, and a pooled subsample (200 g) was used for chemical analyses. Feed chemical analysis procedures were described in Liméa et al. (2009a). The DM content of PR, IM, and SS was determined after 48 h of freeze-drying. The lipid extract content of feed and tissues were determined by ether-petroleum extraction (AOAC, 1997). Feed and tissue FA extractions were carried out according to Bas et al. (2003) and Rule (1997) respectively, using tricosanoic acid as an internal standard in the extraction solvent mixture. Feed and

tissue methylations were described by Bas et al. (2007). Samples were then injected using an auto sampler CP-8410 into a Varian CP-3900 gas liquid chromatograph (GLC, Varian, Les Ulis, France) on a DB-wax fused-silica capillary column (60 m length \times 0.25 mm i.d. \times 0.25 μ m film thickness; JW, Folsom, CA). For the GLC procedure, the split/splitless injector, type 1177, and the flame-ionization detector were held at 250°C. The oven temperature was increased from 120 to 195°C at 4°C/min and then held for 60 min at constant temperature. The injector was in splitless mode for 1.0 min and then in split mode until the end of the run with a split ratio of 30:1. The column flow rate was 1.2 mL/min of He. Fatty acids were identified by comparison with retention time of reference standards (Sigma, St. Louis, MO; Interchim, Montluçon, France) analyzed under similar conditions and integrated using the Star Chromatography Workstation System (version 4.5, Varian Associates Inc., Walnut Creek, CA). The quantification of FA methyl esters was based on the internal standard technique.

Calculations and Statistical Analysis

The FA methyl esters were summed by families according to their structure: even straight-chain SFA (**ESFA**) = C10:0 + C12:0 + C14:0 + C16:0 + C18:0 + C20:0 + C22:0 + C24:0; odd-numbered straight-chain FA (**oddFA**) = C13:0 + C15:0 + C17:0 + C17:1n-8 + C19:0 + C21:0; methyl-branched chain FA of the iso and anteiso forms (**iso and anteiso FA**) = *iso*C14:0 + *iso*C15:0 + *anteiso*C15:0 + *iso*C16:0 + *iso*C17:0 + *anteiso*C17:0; straight-chain MUFA (MUFA) = C14:1 + Σ C16:1 (n-9 and n-7) + Σ C18:1 (n-7, n-9, *trans*-10) + C17:1n-8 + C20:1 + C22:1 + C24:1; n-3 FA = C18:3n-3 + C20:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3; n-6 FA = C18:2n-6 + C18:3n-6 + C20:2n-6 + C20:3n-6 + C20:4n-6 + C22:4n-6; PUFA = n-3 FA + n-6 FA.

Regressions of the different variables against the actual intake of concentrate were computed using the REG procedure (SAS Inst. Inc., Cary, NC) to test linear and quadratic effects. Significance was defined at $P \leq 0.05$.

RESULTS

Growth Performance and Carcass Composition

The growth performance of the 32 kids used for FA composition analyses (Table 2) was not significantly different to the performance of the entire group of 40 kids (Liméa et al., 2009a). Total FA, C16:0, C18:0, and C18:2n-6 intakes (Table 2) increased with increased concentrate supplementation (linear, $P < 0.001$). The C18:1n-9 intake increased with increased concentrate supplementation (linear, $P < 0.001$; quadratic, $P < 0.001$), whereas C18:3n-3 intake was not affected by dietary group. It took animals on the G0 treatment 4 mo longer to reach slaughter weight compared with G300 (400 vs. 275 d, respectively). The ADG increased linearly with amount of concentrate in the diet. Compared with the FF kids, cold carcass weights of CF kids were greater when concentrate increased, with no difference between G100 and G200 groups. The weight of adipose tissue deposits (OF, PR, and IM) increased linearly with amount of concentrate in the diet; the quadratic term was significant only for PR weight. The SS weight was the least for the G0 group and the greatest for the G300 group.

Changes in Adipose Tissue and Muscle FA Proportions with Diet

With increased concentrate, the DM content increased (linear and quadratic, $P < 0.05$) in PR (Table

Table 2. Fatty acid (FA) intakes, performance, and body adiposity of Creole goats fed diets supplemented with 0 (G0), 140 (G100), 240 (G200), or 340 (G300) g of concentrate (n = 8 per group)¹

Item	Diet				SEM	P-value	
	G0	G100	G200	G300		Linear	Quad
FA intake, g·d ⁻¹							
C16:0	0.63	1.15	1.51	1.93	0.087	<0.0001	0.173
C18:0	0.10	0.18	0.23	0.29	0.012	<0.0001	0.296
C18:1n-9	0.11	0.76	1.19	1.63	0.101	<0.0001	<0.0001
C18:2n-6	0.37	0.78	1.07	1.38	0.067	<0.001	0.068
C18:3n-3	0.47	0.44	0.44	0.48	0.009	0.100	0.065
Total FA intake, g of DM·d ⁻¹	1.70	3.31	4.44	5.72	0.270	<0.0001	0.110
ADG, g·d ⁻¹	42	61	74	85	11.0	<0.0001	0.144
Age at slaughter, d	400	334	287	275	8.0	<0.0001	0.090
LWS, kg	22.5	23.7	22.4	23.4	1.80	0.117	0.603
Cold carcass weight, kg	9.0	10.7	11.1	11.6	0.80	<0.0001	0.549
Omental fat, g	190	225	319	454	106.0	0.0021	0.0603
Perirenal fat, g	113	139	255	253	83.0	0.0046	0.0054
Intermuscular fat, g	51	55	74	91	4.4	0.0013	0.058
Supraspinatus muscle, g	62	79	79	84	1.9	<0.0001	0.342

¹Quad = quadratic; LWS = BW at slaughter.

Table 3. Fatty acid (FA) composition of the perirenal adipose tissue of Creole goats fed diets supplemented with 0 (G0), 140 (G100), 240 (G200), or 340 (G300) g of concentrate (n = 8 per group)¹

Item	Diet				SEM	P-value	
	G0	G100	G200	G300		Linear	Quad
DM, %	81.0	81.5	88.1	89.3	1.307	0.042	0.0489
Lipid content, % of DM	92.4	94.2	96.1	98.8	1.516	0.960	0.663
FA composition, g/100 g of FA							
C14:0	2.48	2.54	2.65	2.81	0.061	0.353	0.513
C15:0	1.25	0.83	0.62	0.59	0.052	<0.0001	0.0003
C16:0	21.67	21.80	22.23	22.21	0.226	0.662	0.873
C17:0	2.34	1.87	1.64	1.58	0.056	<0.0001	<0.0001
C18:0	34.96	37.12	35.08	34.80	0.407	0.219	0.140
C19:0	0.19	0.13	0.11	0.10	0.006	<0.0001	<0.0001
C14:1	0.013	0.013	0.016	0.023	0.001	0.719	0.186
C16:1n-7	0.76	0.70	0.76	0.80	0.017	0.257	0.131
C16:1n-9	0.57	0.55	0.48	0.49	0.011	0.142	0.641
C17:1n-8	0.45	0.33	0.34	0.32	0.012	0.0003	0.007
C18:1n-7	6.44	5.52	5.49	5.31	0.105	0.0006	0.019
C18:1n-9	16.44	17.87	19.74	20.37	0.376	0.03	0.45
C18:1 <i>trans</i> -10	ND1	ND2	ND	ND	—	—	—
C18:2n-6	1.42	2.17	2.55	2.82	0.102	<0.0001	0.0051
C18:2 <i>cis</i> -9, <i>trans</i> -11	0.70	0.54	0.61	0.58	0.015	0.0051	0.021
C18:2 <i>trans</i> -10, <i>cis</i> -12	0.011	0.010	0.014	0.013	0.001	0.737	1.00
C18:3n-6	0.47	0.24	0.14	0.14	0.033	0.0005	0.018
C18:3n-3	0.67	0.50	0.41	0.37	0.022	<0.0001	0.0031
C20:2n-6	0.039	0.039	0.038	0.038	0.001	0.5821	0.566
C20:3n-3	0.022	0.017	0.010	0.010	0.001	0.0002	0.048
C20:3n-6	0.109	0.056	0.034	0.029	0.007	<0.0001	0.0004
C20:4n-6	0.059	0.063	0.071	0.073	0.003	0.386	0.740
C20:5n-3	0.031	0.014	0.012	0.011	0.002	<0.0001	0.0014
C22:4n-6	0.155	0.080	0.056	0.049	0.008	<0.0001	<0.0001
C22:5n-3	0.159	0.126	0.088	0.079	0.009	0.046	0.402
C22:6n-3	0.041	0.034	0.028	0.028	0.002	0.129	0.385
ESFA	60.07	62.01	60.60	60.13	0.240	0.021	0.011
MUFA	24.83	25.25	27.00	27.49	0.303	0.226	0.949
PUFA	3.91	3.91	4.10	4.27	0.062	0.960	0.449
Odd FA	4.27	3.20	2.74	2.61	0.120	<0.0001	<0.0001
<i>iso</i> and <i>anteiso</i> FA	4.11	3.31	2.81	2.85	0.109	<0.0001	<0.0001
n-3 FA	0.92	0.69	0.55	0.50	0.033	<0.0001	0.007
n-6 FA	2.27	2.66	2.92	3.18	0.078	0.020	0.521
n-6/n-3	2.49	3.85	5.38	6.55	0.300	0.0004	0.680

¹Quad = quadratic; ESFA = even straight-chain SFA; odd FA = C13:0 + C15:0 + C17:0 + C17:1n-8 + C19:0 + C21:0; *iso* and *anteiso* FA = *iso*C14:0 + *iso*C15:0 + *anteiso*C15:0 + *iso*C16:0 + *iso*C17:0 + *anteiso*C17:0; n-6 FA = C18:2n-6 + C18:3n-6 + C20:2n-6 + C20:3n-6 + C20:4n-6 + C22:4n-6; n-3 FA = C18:3n-3 + C20:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3; ND = not detected; ND1 = not detected except 1 kid in group G0 value = 0.14 g/100 g of FA; ND2 = not detected except 1 kid in group G100 value = 0.30 g/100 g of FA.

3) and decreased in SS (linear, $P < 0.05$). The change in DM content of IM was curvilinear (quadratic, $P < 0.05$, Table 4). The lipid content of PR, IM, and SS was not significantly affected by the different levels of concentrate supplementation.

Individual C14:0, C16:0, and C18:0 proportions were not affected by the different amounts of concentrate supplementation in PR, IM, and SS (Tables 3, 4, and 5); neither were total ESFA proportions in IM and SS. However, ESFA proportion in PR was greater in the G100 group (linear, $P < 0.05$; quadratic, $P < 0.01$) than in the other groups. Total oddFA, C15:0, C17:0, and C19:0, as well as *iso*- and *anteiso*-FA proportions in PR, IM, and SS decreased (linear, $P < 0.001$; quadratic $P < 0.001$) with the greatest proportions being for the G0 group and the least for the G200 and G300 groups.

Total MUFA proportions were not affected by the different concentrate supplementation in PR, IM, and SS. Among MUFA, C16:1n-9 proportion was not affected by diets in PR and SS whereas it decreased linearly ($P < 0.05$) in IM with increased concentrate supplementation. The proportion of C16:1n-7 decreased ($P < 0.02$) linearly with increased concentrate supplementation in SS, whereas it was not modified in PR and IM. The proportion of C17:1n-8 decreased (linear, $P < 0.0001$; quadratic $P < 0.01$) with increased concentrate supplementation in PR and SS, whereas it was not affected by diet in IM. The proportion of C18:1n-9 increased linearly ($P < 0.05$) with increased concentrate supplementation in PR and IM, whereas it was not affected in SS. The proportion of C18:1n-7 decreased in PR, IM, and SS with increased concentrate supplementation. This effect was quadratic in PR ($P < 0.05$) and SS (P

Table 4. Fatty acid (FA) composition of the intermuscular adipose tissue of Creole goats fed diets supplemented with 0 (G0), 140 (G100), 240 (G200), or 340 (G300) g of concentrate (n = 8 per group)¹

Item	Diet				SEM	P-value	
	G0	G100	G200	G300		Linear	Quad
DM, %	58.2	65.4	67.7	66.7	2.323	0.483	0.036
Lipid content, % of DM	75.9	70.4	89.1	80.1	3.14	0.864	0.824
FA composition, g/100 g of FA							
C14:0	2.91	3.22	3.60	3.17	0.120	0.149	0.183
C15:0	1.10	0.74	0.75	0.56	0.047	<0.0001	0.0005
C16:0	22.61	22.76	22.28	23.04	0.199	0.464	0.420
C17:0	2.02	1.61	1.46	1.39	0.048	<0.0001	<0.0001
C18:0	27.31	27.05	21.63	24.35	0.766	0.347	0.669
C19:0	0.26	0.18	0.16	0.14	0.010	<0.0001	0.003
C14:1	0.050	0.056	0.077	0.146	0.015	0.217	0.476
C16:1n-7	1.27	1.21	1.64	1.47	0.065	0.988	0.565
C16:1n-9	0.54	0.51	0.44	0.45	0.011	0.035	0.361
C17:1n-8	0.70	0.56	0.79	0.51	0.048	0.253	0.425
C18:1n-7	5.74	4.85	4.32	4.74	0.132	0.0010	0.010
C18:1n-9	24.51	27.05	30.08	32.16	0.759	0.025	0.169
C18:1 <i>trans</i> -10	ND	ND	ND	ND	—	—	—
C18:2n-6	1.45	2.17	2.35	2.64	0.070	<0.0001	0.0002
C18:2 <i>cis</i> -9, <i>trans</i> -11	1.06	0.82	1.02	0.89	0.026	0.0798	0.152
C18:2 <i>trans</i> -10, <i>cis</i> -12	0.020	0.020	0.022	0.019	0.001	0.128	0.097
C18:3n-6	0.59	0.26	0.20	0.16	0.031	<0.0001	<0.0001
C18:3n-3	0.73	0.55	0.42	0.39	0.026	<0.0001	0.012
C20:2n-6	0.035	0.038	0.038	0.039	0.001	0.392	0.456
C20:3n-3	0.023	0.015	0.015	0.016	0.001	0.0021	0.086
C20:3n-6	0.051	0.026	0.016	0.016	0.003	<0.0001	0.0005
C20:4n-6	0.065	0.086	0.096	0.086	0.003	0.0008	0.003
C20:5n-3	0.035	0.020	0.016	0.013	0.002	<0.0001	0.015
C22:4n-6	0.092	0.065	0.047	0.046	0.004	<0.0001	0.0096
C22:5n-3	0.17	0.15	0.10	0.09	0.008	0.057	0.883
C22:6n-3	0.039	0.034	0.034	0.032	0.002	0.712	0.944
Odd FA	4.11	3.12	3.09	2.62	0.125	<0.0001	<0.0001
<i>iso</i> and <i>anteiso</i> FA	3.51	2.65	2.31	2.43	0.095	<0.0001	<0.0001
ESFA	53.44	53.51	48.00	50.97	0.687	0.317	0.631
MUFA	33.04	34.41	39.62	37.46	0.722	0.0919	0.367
PUFA	4.38	4.27	4.46	4.50	0.059	0.944	0.838
n-3 FA	0.99	0.76	0.58	0.54	0.035	<0.0001	0.021
n-6 FA	2.30	2.68	2.82	3.05	0.067	0.0007	0.082
n-6/n-3	2.32	3.51	4.76	5.77	0.250	0.0001	0.889

¹Quad = quadratic; ESFA = even straight-chain SFA; odd FA = C13:0 + C15:0 + C17:0 + C17:1n-8 + C19:0 + C21:0; *iso* and *anteiso* FA = *iso*C14:0 + *iso*C15:0 + *anteiso*C15:0 + *iso*C16:0 + *iso*C17:0 + *anteiso*C17:0; n-6 FA = C18:2n-6 + C18:3n-6 + C20:2n-6 + C20:3n-6 + C20:4n-6 + C22:4n-6; n-3 FA = C18:3n-3 + C20:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3; ND = not detected.

< 0.01). The C18:1*trans*-10 was only detected in 1 SS sample, in 2 PR samples, and not at all in IM samples.

The proportions of C18:2n-6 and total n-6 FA increased in PR and IM (linear, $P < 0.001$) with increased concentrate supplementation, with the least proportion being for the G0 group and the greatest for the G300 group. In SS, C18:2n-6 and total n-6 FA proportions increased as concentrate supplementation increased from 0 to 140 g (G100) and did not change between G100 and G300 groups (linear, $P < 0.001$; quadratic, $P < 0.05$). The proportions of C18:3n-6 and C22:4n-6 decreased as concentrate supplementation increased from 0 to 240 g (G200), and remained the same between G200 and G300 groups in all tissues (linear, $P < 0.001$; quadratic, $P < 0.05$) except for C22:4n-6 in SS, which increased from 0 to 240 g (G200). The proportion of C20:4n-6 increased between G0 and G100 groups in IM and SS but not in PR. The proportions of

C20:3n-6 increased in SS (linear, $P < 0.001$; quadratic, $P < 0.05$) but decreased (linear, $P < 0.001$; quadratic, $P < 0.001$) in IM and PR, as concentrate supplementation increased from 0 to 140 g (G100) and remained the same between G100 and G300 groups. The C20:2n-6 was not affected by diets in the 3 tissues studied. The proportion of C18:2*cis*-9, *trans*-11 decreased in PR and SS as concentrate supplementation increased from 0 to 140 g (G100; linear, $P < 0.001$; quadratic $P < 0.05$) but remained unchanged in IM.

Total n-3 FA, C18:3n-3, and C20:5n-3 proportions in PR, IM, and SS decreased with increased concentrate supplementation with the greatest proportions being for the G0 group and the least for the G200 and G300 groups (linear, $P < 0.001$; quadratic, $P < 0.01$). The proportion of C22:5n-3 decreased linearly with increased concentrate supplementation, whereas the C22:6n-3 proportion was not affected in PR, IM, and

Table 5. Fatty acid (FA) composition of the supraspinatus muscle of Creole goats fed diets supplemented with 0 (G0), 140 (G100), 240 (G200), or 340 (G300) g of concentrate (n = 8 per group)¹

Item	Diet				SEM	P-value	
	G0	G100	G200	G300		Linear	Quad
DM, %	25.1	23.4	23.5	23.6	0.157	<0.0001	0.234
Lipid content, % of DM	12.6	11.4	10.7	10.7	0.333	0.112	0.348
FA composition, g/100 g of FA							
C14:0	0.22	0.35	0.23	0.27	0.019	0.142	0.124
C15:0	0.60	0.40	0.35	0.31	0.024	<0.0001	0.004
C16:0	19.63	18.72	18.87	18.62	0.266	0.265	0.336
C17:0	1.34	1.05	1.00	0.90	0.034	<0.0001	0.007
C18:0	17.01	17.15	16.23	15.98	0.281	0.937	0.651
C19:0	0.22	0.15	0.12	0.11	0.008	<0.0001	<0.0001
C20:0	0.14	0.12	0.08	0.09	0.006	0.025	0.2851
C14:1	0.09	0.16	0.16	0.19	0.016	0.124	0.307
C16:1n-7	1.61	1.34	1.45	1.58	0.038	0.013	0.010
C16:1n-9	0.53	0.51	0.48	0.48	0.007	0.106	0.471
C17:1n-8	0.92	0.69	0.72	0.65	0.023	<0.0001	0.008
C18:1n-7	4.04	3.41	3.21	3.21	0.061	<0.0001	0.008
C18:1n-9	33.08	33.28	35.54	35.47	0.465	0.335	0.838
C18:1 <i>trans</i> -10	ND	ND	ND1	ND	—	—	—
C18:2n-6	4.19	7.00	6.89	7.71	0.309	0.0004	0.013
C18:2 <i>cis</i> -9, <i>trans</i> -11	1.22	0.85	0.89	0.87	0.033	<0.0001	0.0002
C18:2 <i>trans</i> -10, <i>cis</i> -12	0.031	0.025	0.029	0.031	0.001	0.012	0.006
C18:3n-6	0.45	0.22	0.17	0.17	0.022	<0.0001	<0.0001
C18:3n-3	1.50	1.08	0.72	0.67	0.063	<0.0001	<0.0001
C20:2n-6	0.055	0.063	0.060	0.067	0.002	0.298	0.578
C20:3n-3	0.040	0.069	0.029	0.026	0.008	0.503	0.299
C20:3n-6	0.022	0.227	0.190	0.215	0.015	<0.0001	<0.0001
C20:4n-6	1.04	1.72	1.56	1.77	0.069	0.001	0.021
C20:5n-3	0.46	0.31	0.19	0.17	0.022	<0.0001	0.002
C22:4n-6	0.07	0.13	0.14	0.17	0.007	0.0004	0.069
C22:5n-3	0.74	0.67	0.45	0.45	0.028	0.0051	0.301
C22:6n-3	0.18	0.16	0.15	0.15	0.006	0.094	0.302
ESFA	37.38	36.70	35.92	35.41	0.407	0.464	0.788
MUFA	40.42	39.55	41.00	41.64	0.433	0.999	0.652
PUFA	10.01	12.56	11.52	12.23	0.329	0.049	0.141
<i>iso</i> and <i>anteiso</i> FA	2.86	2.59	2.40	2.42	0.050	0.003	0.046
Odd FA	3.12	2.34	2.21	2.00	0.081	<0.0001	<0.0001
n-3 FA	2.91	2.29	1.53	1.46	0.117	<0.0001	0.008
n-6 FA	5.86	9.39	9.06	10.16	0.381	0.0006	0.016
n-6/n-3	2.01	4.12	5.93	6.93	0.349	<0.0001	0.007

¹Quad = quadratic; ESFA = even straight-chain SFA; odd FA = C13:0 + C15:0 + C17:0 + C17:1n-8 + C19:0 + C21:0; *iso* and *anteiso* FA = *iso*C14:0 + *iso*C15:0 + *anteiso*C15:0 + *iso*C16:0 + *iso*C17:0 + *anteiso*C17:0; n-6 FA = C18:2n-6 + C18:3n-6 + C20:2n-6 + C20:3n-6 + C20:4n-6 + C22:4n-6; n-3 FA = C18:3n-3 + C20:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3; ND = not detected; ND1 = not detected except 1 kid in group G200 value = 0.17 g/100 g.

SS. With increased concentrate supplementation, the n-6/n-3 ratio increased linearly ($P < 0.001$) in PR and IM. This effect was quadratic ($P < 0.01$) in SS.

DISCUSSION

Growth Performance and Carcass Composition

The aim of this study was to quantify the growth performance, body composition, and the changes in FA profiles of different tissues from goat carcasses fed increasing amounts of concentrate and slaughtered at a fixed commercial BW. Consequently, and by design, the goats fed increased concentrate had a younger slaughter age because they had a greater growth rate due to

the greater daily energy intake. The daily NE_g intake increased from 120 MJ·d⁻¹ (group G0) to 250 MJ·d⁻¹ (group G300), and the ADG ranged from 42 to 85 g·d⁻¹. Feeding greater amounts of concentrate increased the carcass weight and the dressing percentage in our study (see companion paper, Liméa et al., 2009a). This was in agreement with studies in local goats in which the animals were slaughtered at a fixed age (Atti et al., 2006; Ryan et al., 2007) or at a fixed BW (Bas et al., 2005; Lee et al., 2008). This could be related to a greater muscle development associated with greater energy and protein intakes, as indicated by the greater weight of SS in the carcass of goats fed increased concentrate in this study, and as observed in our previous study on Creole goats (Liméa et al., 2009b). In association with the greater growth rate and energy intake,

OF, IM, and PR weights were at least doubled between G0 and G300 goats. A similar increase in body fat with increased concentrate supplementation was observed in goats slaughtered at fixed BW (Bas et al., 2005) or at a fixed age (Atti et al., 2006; Ryan et al., 2007), indicating that after partition of energy toward carcass muscle deposition, excess dietary energy was channeled toward lipid deposition, at least in adipose tissues. This was confirmed in the present study (Liméa et al., 2009a). However, lipid proportion in muscle was not affected by level of concentrate because goats fed the all forage-diet had the greatest lipid content in SS, which confirms that lipid deposition in goats is mainly internal (Sahlu et al., 2004), as observed in the companion paper (Liméa et al., 2009a). This study demonstrated that, in the Creole goat breed, feeding increased concentrates increased growth rate and carcass fat content.

In the present paper, FA intake was reduced compared with the lipid intakes (based on ether extract analysis) presented in the companion paper (Liméa et al., 2009a). This was due to the decreased FA content measured in the forage (Table 1).

Overall FA Composition of Adipose Tissues and Muscle of Creole Kids

In the present study, DM of SS was in agreement with data reported on muscles of goats fed hay (Lee et al., 2008), hay and concentrate (Mahgoub et al., 2002), argan pulp (Bas et al., 2005), or grazed grass supplemented with concentrate (Werdi Pratiwi et al., 2007). However, the Creole goat kids had greater SS lipid content (11 to 13% of DM) compared with most reported data: 5 to 6% of muscle DM reported by Werdi Pratiwi et al. (2007) and Lee et al. (2008), and 7 to 9% reported by Bas et al. (2005) and Atti et al. (2006). Only Mahgoub et al. (2002) reported a greater lipid content (20% of DM in goats around 20 kg of BW) compared with our study. Such variations are related to differences in the age and breed of goats studied, as well as to feeding level and energy density of diets (Wood et al., 2008). Moreover, muscle differences (mostly LM vs. SS in the present trial) and differences in fat trimming procedures may also be responsible for these differences (Bas et al., 2005). In the present study, the DM and lipid content of PR were in the high range of reported measurements in goats (Banskalieva et al., 2000; Mahgoub et al., 2002; Bas et al., 2005; Werdi Pratiwi et al., 2007). To our knowledge, few data are available on IM, for comparison.

The G0 goats had similar ESFA proportions in IM and PR adipose tissues (between 50 and 60% of total FA) but proportions below 40% in SS. These proportions are in agreement with data in goats fed argan pulp (Bas et al., 2005), but slightly less than those in muscle and adipose tissues of goats fed concentrate and hay (Mahgoub et al., 2002), browse-based diet (Ryan et al., 2007), or grazed grass supplemented with concentrate (Werdi Pratiwi et al., 2007). In this study, C18:0

was the predominant FA in PR, whereas, in SS and IM, C16:0 and C18:0 were in similar proportions. In goats fed concentrate and hay, C16:0 was greater than C18:0 in the muscle (Mahgoub et al., 2002; Ryan et al., 2007; Werdi Pratiwi et al., 2007) but in similar proportions in PR (Mahgoub et al., 2002). However, goats fed argan pulp had similar proportions of C16:0 and C18:0 in both PR and muscle (Bas et al., 2005). In all studied tissues of the Creole goats and especially in SS, the C14:0 proportion was reduced, and less than most of the published values (Mahgoub et al., 2002; Bas et al., 2005; Atti et al., 2006; Werdi Pratiwi et al., 2004, 2007). Because consumption of C14:0 has been implicated in increasing plasma cholesterol, meat from indigenous Caribbean goats with its reduced C14:0 may have positive health implications.

In our Creole goats, the proportions of n-3 FA were classically greater in the muscle than in the adipose tissues because muscle has a greater phospholipid content than adipose tissues, phospholipids that are characterized by greater 18:3n-3 and n-3 FA proportions than storage lipids (Wood et al., 2008). The most represented FA in all studied tissues was 18:3n-3, but the most biologically significant FA are C20:5n-3, C22:5n-3, and C22:6n-3 when dietary recommendations for human health are considered (Wood et al., 2008). From this point of view, total n-3 FA in muscle and PR were in the range observed in goats fed argan pulp (Bas et al., 2005), but less than those observed in muscle of goats fed a browse diet (Ryan et al., 2007). Differences in n-3 FA proportions between these experiments may be related to differences in the C18:3 content of experimental diets, as well as in ruminal physico-chemical conditions that affect ruminal biohydrogenation of PUFA (Glasser et al., 2008). Data on C20:5n-3, C22:5n-3, and C22:6n-3 are scarce for goat muscle and adipose tissues (Lee et al., 2008).

Proportions of n-6 FA in edible tissues are usually greater than those of n-3 FA, as dietary C18:2n-6 is less biohydrogenated than dietary C18:3n-3 (Glasser et al., 2008), and as C18:2n-6 and its long-chain products C20:4n-6 and C22:4n-6 are preferentially deposited in phospholipids compared with n-3 FA (Wood et al., 2008). Total n-6 FA, C20:4n-6, and C22:4n-6 proportions in muscle and PR of our Creole goats were less than those reported by Bas et al. (2005), but were in the range of those reported for C18:2n-6 in muscle and PR (Mahgoub et al., 2002; Lee et al., 2008). With respect to n-3 FA, these results may be explained by differences in dietary C18:2 intake and conditions of ruminal biohydrogenation.

Trans-FA in goat muscle or in adipose tissues have been scarcely reported in the literature, especially for the profile of *trans*-C18:1 FA. In our study, only C18:1*trans*-10 can be quantified, C18:1*cis*-11 and C18:1*trans*-11 co-elute on the DB-Wax column used (Kramer et al., 2002; Alves and Bessa, 2009) and cannot be quantified separately. Other positional isomers of C18:1*trans* FA in muscle or adipose tissues cannot

be obtained because they are not well separated from each other. Under these conditions, C18:1*trans*-10 was never detected in SS or in IM from G0 goats, and only 1 goat fed this diet exhibited a value above the threshold of sensitivity of our method in the PR tissue. In goats fed the all-forage diet, these results are consistent with the fact that C18:1*trans*-10 mainly reflects changes in the ruminal biohydrogenation process of FA associated with changes in pH and microbial populations (Harfoot and Hazlewood, 1997; Jenkins et al., 2008) induced by feeding high-grain diets, for example in lambs (Bas et al., 2007). This is confirmed by the very low concentration of the *trans*-10, *cis*-12 isomer of the CLA (0.01 to 0.03 in the muscle or in the adipose tissues) that is generally produced when high-grain diets are fed. The proportions of C18:2*cis*-9, *trans*-11 were in the greater range of values reported in lambs (Bas et al., 2007).

The proportions of C18:1*n*-9 tended to be less than in other studies on growing goats (Casey and Van Niekerk, 1985; Mahgoub et al., 2002; Dhanda et al., 2003; Werdi Pratiwi et al., 2004). The total oddFA plus *iso*- and *anteiso*-FA proportions ranged from 4.4 to 8.4% of the total FA in all tissues with progressively increased proportions in SS, IM, and PR, respectively. These results are in the greater range of what is usually observed but agreed with results of Bas et al. (2005) in young Morocco goats in semi-intensive conditions.

Effect of Increased Concentrate Supplementation on FA Composition of Adipose Tissues and Muscle in Creole Goats

In this experiment, increased concentrate supplementation significantly increased the DM content of PR and tended to increase the DM content of IM, with only small changes in their lipid content. This could be due to a faster growth of adipocyte size for these younger goats at greater energy intakes. Conversely, increased concentrate supplementation slightly decreased the DM and lipid contents of SS. This is in contrast to several studies that have reported greater DM and muscle fat contents in goats (Bas et al., 2005; Lee et al., 2008) or in lambs (Bas et al., 2007) fed increased concentrate. Nevertheless, some studies also reported no changes in DM or in lipid contents of muscle of goats fed different levels of concentrate (Atti et al., 2006). The discrepancy between this study and others could be explained by the type of muscle studied (LM in most experiments vs. SS in our study) but also by the younger age of the goats fed concentrate. For instance, Mahgoub et al. (2002) and Werdi Pratiwi et al. (2007) reported that DM or lipid contents in adipose tissue or in muscle increased with increased age of growing goats (increased BW).

Increased concentrate supplementation did not increase the proportions of C14:0 and C16:0 in PR, IM, and SS, which is desirable for human nutrition (Micha and Mozaffarian, 2010). Moreover, it did not affect

C18:0 and ESFA proportions in IM and SS, although in PR there was a small (maximal 2%) increase in the G100 group compared with the average proportion of ESFA (60%) observed in the other experimental groups. Increased concentrate supplementation has given rise to inconsistent results in the literature. Proportions of ESFA, C14:0, C16:0, and C18:0 were not affected by concentrate levels in IM lipids of goats (Atti et al., 2006; Lee et al., 2008), whereas these FA were greatly increased in the muscle of goats fed increasing percentages of concentrate (Ryan et al., 2007), or decreased in the muscle of grain-fed goats compared with range goats (Rhee et al., 2000). Moreover, these FA could be differently affected according to the tissue considered, as observed by Bas et al. (2005). This author reported only small changes in C14:0 and C16:0 but a decrease of C18:0 and ESFA proportions in muscle, but not in PR tissue, of goats fed argan pulp with increased percentage of concentrate. Because part of the C16:0 and most of the C18:0 in adipose tissue and muscle arise from dietary FA, differences among experiments may reflect differences in FA intake, differences in PUFA intake, as well as differences in ruminal biohydrogenation of the PUFA and transfer into the tissues being considered (Geay et al., 2001). Moreover, differences may also be due to the preweaning diet (milk FA composition), especially for C14:0, because FA of body fat stored before weaning influenced the FA composition of fat deposits and muscle several months after weaning (Bas and Morand-Fehr, 2000). However, all these data suggest that feeding concentrate has little, if any, effect on SFA proportions in edible parts of goat meat.

The C15:0, C17:0, and C19:0 proportions as well as *iso*- and *anteiso*-FA proportions decreased with increased concentrate level in all studied tissues, the PR being the most affected and SS being the least affected. These results are in agreement with a decrease in oddFA and methyl branched-chain FA proportions observed with increased concentrate level in most studies in goats (Bas et al., 2005; Lee et al., 2008), but not in all studies (Atti et al., 2006; Ryan et al., 2007). This probably reflects the decrease of microbial synthesis of FA in the rumen as these FA mainly originate from ruminal lipid microbial synthesis (Vlaeminck et al., 2006), especially when diets have increased NDF contents (Bas et al., 2003). With regard to health aspects, the decrease in oddFA can be considered as neutral because these FA are not known to have any effect on health.

In the present experiment, the commercial concentrate was rich in C18:2*n*-6 due to the components used (corn and soybean cake), and as stated above, greater intakes of C18:2*n*-6 were observed in goats fed increased concentrate supplementation. Despite extensive ruminal hydrogenation of C18:2*n*-6 in the rumen (on average 90%, Glasser et al., 2008), the differences in the proportions of C18:2*n*-6 in the studied tissues reflected the changes in its dietary intake. Surprisingly, the C18:3*n*-3 intake was not different between groups.

This was due to the rather low C18:3 content of the forage (1.1 g·kg⁻¹ of DM) and to the only slight decrease of forage intake when concentrate was fed (maximum -50 g·d⁻¹, which means -55 mg of C18:3·d⁻¹). This slight decrease was compensated by the C18:3 from concentrate intake. Generally, goats fed grass pasture or forage had greater C18:3n-3 proportions in fat deposits and muscle than animals fed concentrate based-diets when these concentrates are poor in C18:3n-3 (Bas et al., 2005; Lee et al., 2008). This was not the case when concentrates were rich in C18:3 (Bas et al., 2007), which reflected a positive relationship between intake of C18:3n-3 and its proportion in meat (Wood et al., 2008). In our study, the goats fed the forage diet had slightly greater C18:3n-3 proportions in all studied tissues, despite a similar intake when compared with the concentrate fed-groups. This may have been due to a reduction in C18:3n-3 ruminal biohydrogenation (95% on average, Glasser et al., 2008) in the rumen of goats fed *D. decumbens* by a mechanism that remains to be elucidated or a dilution effect caused by the absorbed C18:3n-3 being distributed in a greater amount of lipid in the kids fed concentrates (this assumes that duodenal flows of C18:3n-3 remained the same between groups).

The decrease in 18:3n-3 proportions with increased level of concentrate supplementation was associated with decreased proportions of the different n-3 FA (C20:3n-3, C20:5n-3, and C22:5n-3, but not for the C22:6n-3) in all studied tissues. The increase in C18:2n-6 proportions with increased concentrate supplementation were also associated with an increase in C20:4n-6 in IM and SS but not in PR. All these results are in line with previous results on long-chain PUFA in tissues of goats or lambs fed diets with increased C18:2/C18:3 intake (Aurousseau et al., 2004; Bas et al., 2005, 2007; Ryan et al., 2007; Lee et al., 2008). Therefore the n-6/n-3 ratio significantly increased in PR, IM, and SS from G0 to G300. With regard to the recommendation of a n-6/n-3 ratio below 4 (Wood et al., 2008) to improve the nutritional value of meat, the most favorable meat based on the ratio in IM and SS was that produced from Creole goats fed 0 to 140 g of commercial concentrate.

The proportions of C18:2*cis*-9, *trans*-11 were greater in forage-fed goats than concentrate-fed goats in PR and SS. This agrees with results obtained on muscles of lambs fed grass or concentrate (Nuernberg et al., 2005; Aurousseau et al., 2007). Similar results were reported in steers fed increased concentrate on grass-based diets (French et al., 2000); they were related to a decrease in the C18:1*trans*-11-producing bacteria at a similar C18:2n-6 intake (French et al., 2000). Factors that determine the amount of *cis*-9, *trans*-11 C18:2 in the tissues are the dietary intake of C18:2, the rumen conditions that may affect the growth and activity of C18:1*trans*-11-producing bacteria (*Butyrivibrio fibrisolvens*; Klieve et al., 2003), and the Δ^9 -desaturase enzyme that desaturates C18:1*trans*-11 to C18:2*cis*-9,

trans-11 C18:2 in the muscular and adipose tissues. Moreover, a C18:2n-6 increase in diet has also been shown to increase the C18:2*cis*-9, *trans*-11 proportion in tissues (Beaulieu et al., 2002; Bas et al., 2007). Consequently, an increase in C18:2*cis*-9, *trans*-11 proportion in tissues of goats could also have been expected in our study. This was not the case, possibly because of the changes in fermentation patterns associated with high-concentrate diets or because of the dilution of this FA in the greater lipid content of PR and IM on these diets. It has been shown that high-concentrate diets promote the growth of the bacterial strain *Megasphaera elsdenii* with *cis*-9, *trans*-10 isomerase activity resulting in C18:1*trans*-10 production, at the expense of *B. fibrisolvens*, which has a *cis*-9, *trans*-11 isomerase activity (Klieve et al., 2003) resulting in C18:1*trans*-11 production. However, we failed to detect the C18:1*trans*-10 in most tissues except in very few goats in our study, which is also in agreement with the absence of variation of C18:2*trans*-10, *cis*-12 in all tissues with concentrate supplementation. More probably, limited C18:1*trans*-11 availability from ruminal fermentation to muscle and adipose tissues may have resulted in a reduced proportion of C18:2*cis*-9, *trans*-11 in these tissues in our study. Indeed, we observed a decreased in C18:1n-7 proportions in all tissues. However, we were unable to distinguish between *cis*-11 and *trans*-11 C18:1. Because the C18:1n-7 corresponded to the sum of the C18:1*cis*-11 and C18:1*trans*-11, it is difficult to conclude which FA is involved in that variation. Even though Faucitano et al. (2008) showed that increased dietary concentrate increased the proportion of C18:1*cis*-11 in the muscle of steers, the greater variation of n-7 observed between groups might be due to the *trans*-11 isomer as in PR and muscle C18:1n-7 and C18:2*cis*-9, *trans*-11 were positively correlated ($r = 0.545$ in PR and 0.732 in SS; $P < 0.001$). Consequently, limited availability of C18:1*trans*-11 may account for the reduced C18:2*cis*-9, *trans*-11 proportions in all studied tissues.

The C18:1n-9 proportion in adipose tissues increased with increased concentrate supplementation. This result is in agreement with other studies (Rhee et al., 1997; Bas et al., 2005; Ryan et al., 2007; Faucitano et al., 2008). The C18:1n-9 in tissues originates partly from this FA intake not being completely biohydrogenated in the rumen, and partly from de novo conversion of C18:0 by the Δ^9 -desaturase enzyme in tissues. In the present study, a significant increase in C18:1n-9 intake was observed with increased concentrate supplementation. The best estimate of this enzyme activity is the Δ^9 -desaturase activity proxy, which is calculated as **ID14** ($\text{ID14} = \text{C14:1cis-9} \times 100 / \text{C14:0} + \text{C14:1cis-9}$). When calculating the Δ^9 -desaturase activity proxy, significant increases were observed with increasing intake of concentrate in PR (G0: 0.52; G100: 0.51; G200: 0.63; G300: 0.79) and in IM (G0: 1.72; G100: 1.68; G200: 2.50; G300: 2.44). This therefore suggests that desaturase enzyme activity could have been induced but not completely proportional to levels of concentrate, prob-

ably in response to an increased desaturase gene expression induced by insulin (Daniel et al., 2004) and downregulated by PUFA (Bas et al., 2005). However, contrary to results from adipose tissues, we failed to show any differences in the C18:1n-9 proportion in SS with increased concentrate supplementation. However, a significant increase of the ID14 proxy with levels of concentrate was measured (G0: 29.5; G100: 27.5; G200: 40.9; G300: 40.6) in muscle.

In this study, the growth performance and FA composition of adipose tissues and muscle from male indigenous Caribbean goats were altered by feeding increased concentrate. This was due to the differences in energy and FA intake, and possibly also to the age of the animals slaughtered at a constant BW. From a nutritional point of view, meat from Creole goats fed the all-forage diet was similar to that of other goat breeds fed similar diets. Increased concentrate supplementation did not affect the proportion of MUFA, increased PUFA in muscle, and had very few effects on ESFA in tissues. One of the major modifications of FA composition was the decrease in n-3 PUFA and increase in n-6 PUFA in all tissues with increased concentrate supplementation. When evaluating the effect of changes in FA composition with regard to human health, concentrate supplementation did not increase any cholesterol-raising SFA in meat, but increased the n-6/n-3 ratio above 4 when more than 200 g of concentrate was added to the diet. Therefore, it is recommended to feed concentrates at levels less than 240 g/d to have FA compositions that are desired for current human nutrition guidelines.

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