Effect of Feeding Highly Cis-Monounsaturated, Trans, or *n*−3 Fats on Lipid Composition of Muscle and Adipose Tissue of Pigs

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The effects of feeding various fat sources on contents of trans fatty acids (TFA) and *n*−3 polyunsaturated fatty acids (*n*−3 PUFA) and on cholesterol incorporation in muscle and adipose pork tissue were studied. Thirty castrated pigs, divided into three experimental groups receiving the same basal diet with a different 4% supplement of fat—hydrogenated oil (H), linseed oil (L), and pomace oil (O)—were slaughtered at 95 ± 2.16 kg. No differences were observed in production performance and in carcass and meat characteristics. The pattern of dietary fatty acids was reflected in muscle and adipose tissues. In backfat, animals fed H had the highest TFA contents. Animals fed O had the highest MUFA contents. Animals fed L had the highest levels of *n*−3, greater contents of C20:5*n*−3 (eicosapentaenoic acid) and C22:5*n*−3, and lower levels of arachidonic acid (C20:4*n*−6). Dietary treatment did not affect cholesterol concentration.

Keywords: *Trans fatty acid; cis MUFA; n−3 PUFA; pig carcass*

INTRODUCTION

It has long been known that in pigs, a monogastric animal, the fatty acid composition of carcass lipid deposits can be modified by diet. This possibility may be used in order to improve the fatty acid composition according to the current diet/health guidelines.

St. John et al. (1987) and Myer et al. (1992) have studied the effect of using diets high in monounsaturated fatty acids (MUFA) with no reference to configuration. There has been a growing interest in the trans configuration due to the similarities in their effect on human health with saturated fatty acids (British Task Force, 1995).

It is possible to increase the levels of *n*−3 and *n*−6 polyunsaturated fatty acid (PUFA) series in pork products (Morgan et al., 1992; Romans et al., 1995). The proportion of *n*−6 to *n*−3 PUFA in the diet is important in the regulation of the metabolism of eicosanoids and therefore in the development of certain diseases (Sanders, 1990). Little information on the cholesterol concentration in different porcine muscles is available, and information on the effect of feeding different types of fats on these concentrations is also scarce.

The purpose of this study was to observe the effects of ingesting diets high in tran fatty acids (TFA) and *n*−3 PUFA vs a diet high in cis MUFA on the muscle and adipose tissues of the pig carcass. Specifically, deposition rates of isolated fatty acids were determined, as well as their interaction and possible effects on cholesterol levels.

MATERIALS AND METHODS

Animals and Experimental Diets. Thirty castrated male Landrace*Duroc cross-bred pigs were distributed randomly according to weight and original litter to one of three experimental groups (two replicates of five animals in each group) and fed the same basal diet of corn, barley, and soybean meal (NRC, 1988; Table 1). Each animal's diet was supplemented with 4% fat (by weight) as either pomace oil (O), hydrogenated oil (H), or linseed oil (L) (Table 2). The experiment began when the animals were approximately 80 days old and weighed 26 ± 4.3 kg. After 82 days on the experimental diets, animals were slaughtered at a live weight of 95.56 ± 2.16 kg.

Table 1. Composition of the Basal Diet

Ingredients (%)	
wheat	27.76
barley	34.00
wheat bran	15.00
soybean meal, 47%	13.94
meat, 50%	2.00
added fat[b]	4.00
salt	0.50
calcium carbonate	0.74
dicalcium phosphate	1.20
methionine, 98%	0.02
lysine, 78%	0.22
vitamin and mineral premix	0.63
Analysis	
crude energy (kcal/kg)	4210.12
digestible energy (kcal/kg)[a]	3279.30
dry matter (%)	89.45
crude protein (%)	16.80
crude fiber (%)	4.69
total fat (%)	6.24
ash (%)	6.06
lysine (%)[a]	0.95
methionine (%)[a]	0.29
methionine + cystine (%)[a]	0.59
calcium (%)[a]	0.80
phosphorus (%)[a]	0.63

[a] Estimated.

Throughout the experiment food and water were provided *ad libitum*. The experiment was carried out at the Experimental Unit of the Faculty of Veterinary Science of the Universitat Autònoma de Barcelona in environmental conditions suitable to normal conduct of the trials.

Carcass Measurements. The animals were slaughtered in a commercial slaughterhouse (Escorxador Frigorífic d'Osona, ESFOSA), and carcasses were weighed and evaluated. A Fat-O-Meter (SFK Ltd., Denmark) was used to measure carcass fat thickness 6 cm from the midline at two different points, between the third and fourth ribs and at the last rib, and the

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Table 2. Fatty Acid Composition of Experimental Diets Containing Pomace Oil (O), Hydrogenated Oil (H), and Linseed Oil (L)

fatty acid (%)	treatment		
	O	H	L
C10:0	0.03	0.06	0.05
C12:0	0.05	0.06	0.08
C14:0	0.33	0.30	0.40
C15:0	0.10	0.09	0.12
C16:0	14.20	16.27	14.09
C16:1*n*−7t	0.04	0.05	0.05
C16:1*n*−9	0.16	0.07	0.10
C16:1*n*−7	0.63	0.28	0.32
C17:0	0.19	0.14	0.19
C18:0	3.88	10.27	4.65
C18:1*n*−9t	0.76	19.56	0.48
C18:1*n*−9	54.34	25.88	22.72
C18:1*n*−7	1.66	2.10	1.35
C18:2*n*−6t	0.16	0.83	0.13
C18:2*n*−6	19.68	20.40	27.58
C20:0	0.41	0.40	0.26
C18:3*n*−6	0.03	0.03	0.53
C20:1*n*−9	0.50	0.37	0.55
C18:3*n*−3	1.72	2.57	25.79
C20:2*n*−6	0.88	0.09	0.15
C20:3*n*−6	0.00	0.00	0.06
C20:3*n*−3	0.00	0.00	0.16
C20:4*n*−6	0.00	0.00	0.06
C20:5*n*−3	0.06	0.04	0.22
C22:4*n*−6	0.02	0.02	0.06
C22:5*n*−3	0.12	0.09	0.18
C22:6*n*−3	0.07	0.05	0.11
SFA	19.18	27.58	19.80
MUFA	57.28	28.69	24.98
PUFA	22.58	23.28	54.58
PUFA/SFA	1.28	0.85	2.82
trans	0.96	20.44	0.63
n−6/*n*−3	10.38	7.74	1.14

percentage of lean meat was calculated. As indicators of meat quality the pH (HI-9025 microcomputer, Scharlau, Denmark) and the electrical conductivity (pork quality meter, Giralada, Munich, Germany) of the longissimus muscle were measured 45 min postmortem (Oliver et al., 1991). Carcasses were classified in the slaughterhouse according to weight and a visual assessment of their state of fatness condition (from 1, which refers to extremely lean carcass, to 5, which means extremely fatty carcass).

Sampling. For the lipid and cholesterol analyses, six animals were chosen from each replica (24 pigs). Four tissue samples (two muscle tissues, longissimus and trapezius, and two adipose tissues, backfat and abdominal fat) were taken at 24 h postmortem from each pig, totaling 72 samples. The samples were kept at −80 °C until analysis.

Analysis of Fatty Acids. Lipids from experimental diets and tissue samples were extracted (Folch et al., 1957), and fatty acid methyl esters were prepared by esterification with sodium methylate (0.5 N) and 20% boron trifluoride/methanol solution (AOAC, 1990). The fatty acid methyl esters were separated on a Perkin Elmer autosystem gas chromatograph equipped with a silica gel precolumn (0.25 mm i.d. × 2.5 m) with deactivated cyanopropyl/phenyl/methyl silica and a silica gel capillary column (0.25 mm i.d. × 50 m) with a 0.2 mm internal coating of cyanopropyl silica (CP-Sil 88, Chrompak). The conditions used were as follows: temperature program, 11.2 min at 177 °C, from 177 to 225 °C at 7 °C/min, and then 11 min at the latter temperature; injector temperature, 270 °C; detector temperature, 300 °C; a split ratio of 1:30 and volume sample of 0.2−0.5 μL were used. Identification was made by comparison with known retention times of the corresponding pure standards. Quantification was carried out through internal normalization. A joint value is given for the different trans isomers of linoleic acid, C18:2*n*−6 cis-trans, C18:2*n*−6 trans-trans and C18:2*n*−6 trans-cis, since they were not entirely separated under these chromatographic conditions.

Table 3. Production and Carcass Characteristics of Pigs Fed Diets Containing Pomace Oil (O), Hydrogenated Oil (H), and Linseed Oil (L)[a]

item	dietary treatment			SE	P
	O	H	L		
FI (kg/day)	2.66	2.40	2.50	0.083	0.24
ADG (kg/day)	0.84	0.84	0.82	0.023	0.54
FE	3.17	2.88	3.06	0.092	0.47
final wt (kg)	95.52	94.73	93.78	2.16	0.77
carcass wt (kg)	71.05	71.44	68.75	2.36	0.66
carcass yield (%)	75.00	74.16	73.69	0.45	0.11
carcass score	3.40[a]	2.67[b]	2.90[a]	0.20	0.03
3−4 rib fat depth (mm)	25.70	22.66	23.50	1.09	0.13
last rib fat depth (mm)	23.60	20.66	21.30	1.20	0.19
m.longissimus diameter (mm)	44.70	46.66	45.10	1.15	0.44
lean %	46.01	48.99	48.00	0.91	0.07
pH	6.13	6.13	6.03	0.07	0.52
electric conductivity	3.80	4.02	4.09	0.21	0.39

[a] SE, standard error; FI, feed intake; ADG, average daily gain; FE, feed efficiency. Carcass score was based on a 5-point scale, where 1 refers to extremely lean carcass and 5 extremely fatty carcass. Means in the same row that do not have a common superscript (a, b) are different ($P < 0.05$).

Cholesterol Determination. Cholesterol determination in muscle samples was made after freeze-drying (Dura-Dry, FTS Systems, Stone Ridge, NY) and cholesterol extraction using the technique described by Guardiola et al. (1994). Separation and identification of cholesterol was carried out on a Shimadzu GC-14A gas chromatographer equipped with a 30 m methyl silica capillary column of 0.25 mm i.d. (SP-2330, Supelco). The temperature program was 5 min at 270 °C, then up to 300 °C at 30 °C/min, and 4 min at the latter temperature. Detector and injector temperatures were 300 °C, and volume injected was 0.5 μL.

Statistical Analysis. Fatty acid weight percentages, cholesterol concentrations, growth performance and carcass measurements, were subjected to ANOVA by using the GLM procedure of SAS (SAS, 1994). Type of dietary fat and anatomical location were independent variables. For significant differences ($P < 0.05$) means were compared using the LSD method of the same statistical package.

RESULTS AND DISCUSSION

Growth Performance and Carcass Characteristics. Production and carcass characteristics are shown in Table 3. The type of supplemental fat produced no differences ($P > 0.05$) in any of the parameters except carcass score. Similar findings by others were reported for growth performance (Leszczynsky et al., 1992; Romans et al., 1995) and in carcass characteristics (Miller et al., 1990; Myer et al., 1992).

The percentage of lean in animals fed H was great (H, 48.99%; O, 46.01%; L, 48.00%; $p = 0.073$). This value was associated with the subjective classification of the carcass, which gave the highest score to H-fed animals. At the slaughterhouse these carcasses seemed visually to have a whiter and harder fat. This could be because the trans fatty acids have a higher melting point than their cis isomers. Electrical conductivity and postmortem pH were not affected by treatment and were within normal ranges.

Fatty Acid Weight Percentages. The fatty acid weight percentages of adipose and muscle tissues are given in Tables 4−7. In general, the dietary fatty acid composition had a clear effect on the lipid weight concentration of the different animal tissues. In each experimental group, all four tissues had concentrated levels of dietary fatty acids. Others have observed this in adipose tissues. Miller et al. (1990) found high percentages of oleic acid (54.80%) using 10% safflower

Table 4. Fatty Acid Composition of Longissimus Muscle from Pigs Fed Diets Containing Pomace Oil (O), Hydrogenated Oil (H), and Linseed Oil (L)[a]

fatty acids (%)	treatment			SE	P
	O	H	L		
C10:0	0.12	0.15	0.12	0.016	0.238
C12:0	0.10	0.10	0.08	0.008	0.073
C14:0	1.29[ab]	1.39[a]	1.16[b]	0.046	0.007
C15:0	0.18	0.23	0.19	0.072	0.859
C16:0	22.76[a]	23.07[b]	21.01[b]	0.427	0.005
C16:1*n*−7t	0.36[a]	0.17[b]	0.04[a]	0.011	0.001
C16:1*n*−9	0.37[a]	0.34[a]	0.24[b]	0.018	0.001
C16:1*n*−7	2.16	2.36	1.91	0.179	0.193
C17:0	0.22	0.23	0.23	0.016	0.903
C18:0	12.36	13.49	12.28	0.528	0.184
C18:1*n*−9t	0.30[a]	3.42[b]	0.27[a]	0.389	0.001
C18:1*n*−9	45.10[a]	38.37[b]	35.73[c]	0.916	0.001
C18:1*n*−7	2.60[ab]	2.91[a]	2.36[b]	0.146	0.034
C18:2*n*−6t	0.09[a]	0.40[b]	0.08[a]	0.030	0.001
C18:2*n*−6	8.74[a]	9.17[a]	11.21[b]	0.672	0.033
C20:0	0.20	0.23	0.21	0.014	0.363
C18:3*n*−6	0.04[a]	0.06[a]	0.17[b]	0.017	0.001
C20:1*n*−9	0.87[a]	0.72[b]	0.65[b]	0.035	0.001
C18:3*n*−3	0.71[a]	1.10[a]	9.04[b]	0.443	0.001
C20:2*n*−6	0.42[a]	0.44[a]	0.54[b]	0.031	0.024
C20:3*n*−6	0.13	0.14	0.11	0.017	0.545
C20:3*n*−3	0.12[a]	0.17[a]	1.23[b]	0.041	0.001
C20:4*n*−6	0.69	0.83	0.32	0.177	0.111
C20:5*n*−3	0.07[a]	0.11[a]	0.27[b]	0.031	0.001
C22:4*n*−6	0.13	0.16	0.10	0.025	0.217
C22:5*n*−3	0.13[a]	0.22[a]	0.43[b]	0.042	0.001
C22:6*n*−3	0.07	0.07	0.07	0.011	0.988
SFA	33.23[ab]	38.89[a]	35.26[b]	0.767	0.009
MUFA	51.10[a]	44.69[b]	40.89[c]	1.069	0.001
PUFA	11.24[a]	12.45[a]	23.47[b]	1.133	0.001
TFA	0.43[a]	3.98[b]	0.38[a]	0.422	0.001
n−3	1.10[a]	1.67[a]	11.02[b]	0.488	0.001
n−6	10.15	10.78	12.45	0.752	0.094
PUFA/SFA	0.30[a]	0.32[a]	0.67[b]	0.376	0.001
n−6/*n*−3	9.31[a]	6.71[b]	1.14[c]	0.356	0.001

[a] SE, standard error. Means in the same row that do not have a common superscript (a−c) are different ($P < 0.05$).

Table 5. Fatty Acid Composition of Trapezius Muscle from Pigs Fed Diets Containing Pomace Oil (O), Hydrogenated Oil (H), and Linseed Oil (L)[a]

fatty acids (%)	treatment			SE	P
	O	H	L		
C10:0	0.10	0.11	0.12	0.008	0.590
C12:0	0.07	0.08	0.07	0.003	0.907
C14:0	1.14	1.17	1.10	0.036	0.373
C15:0	0.14[a]	0.06[b]	0.12[a]	0.017	0.039
C16:0	21.91	22.20	20.83	0.453	0.082
C16:1*n*−7t	0.03[a]	0.17[b]	0.38[a]	0.007	0.001
C16:1*n*−9	0.37[a]	0.35[a]	0.27[b]	0.016	0.001
C16:1*n*−7	1.90	1.92	1.74	0.094	0.316
C17:0	0.25	0.27	0.24	0.020	0.569
C18:0	13.28	14.27	13.18	0.600	0.332
C18:1*n*−9t	0.23[a]	3.72[b]	0.29[a]	0.118	0.001
C18:1*n*−9	44.78[a]	38.95[b]	34.95[c]	1.091	0.001
C18:1*n*−7	2.33	2.47	2.27	0.095	0.281
C18:2*n*−6t	0.08[a]	0.40[b]	0.09[a]	0.012	0.001
C18:2*n*−6	9.51	9.83	11.73	0.775	0.099
C20:0	0.19	0.21	0.19	0.011	0.115
C18:3*n*−6	0.04[a]	0.03[a]	0.16[b]	0.007	0.001
C20:1*n*−9	0.93[a]	0.82[b]	0.69[c]	0.024	0.001
C18:3*n*−3	0.86[a]	1.21[a]	8.77[b]	0.349	0.001
C20:2*n*−6	0.50	0.57	0.61	0.034	0.102
C20:3*n*−6	0.14	0.12	0.13	0.012	0.381
C20:3*n*−3	0.15[a]	0.21[a]	1.28[b]	0.044	0.001
C20:4*n*−6	0.61[a]	0.44[b]	0.30[c]	0.046	0.001
C20:5*n*−3	0.05[a]	0.05[a]	0.22[b]	0.019	0.001
C22:4*n*−6	0.16[a]	0.16[a]	0.10[b]	0.013	0.007
C22:5*n*−3	0.15[a]	0.17[a]	0.46[b]	0.029	0.001
C22:6*n*−3	0.08	0.07	0.08	0.008	0.731
SFA	37.09	38.36	35.85	0.978	0.175
MUFA	50.31[a]	44.50[b]	39.92[c]	1.145	0.001
PUFA	12.25[a]	12.86[a]	23.82[b]	1.235	0.001
TFA	0.35[a]	4.28[b]	0.42[a]	0.133	0.001
n−3	1.29[a]	1.71[a]	10.80[b]	0.434	0.001
n−6	10.97	11.15	13.02	0.847	0.163
PUFA/SFA	0.33[a]	0.34[a]	0.67[b]	0.043	0.001
n−6/*n*−3	8.75[a]	6.84[b]	1.20[c]	0.517	0.001

[a] SE, standard error. Means in the same row that do not have a common superscript (a−c) are different ($P < 0.05$).

oil (72.1% of oleic acid in the diet); Cherian and Sim (1995) found linolenic acid levels of 10.3%, using 17.5% linseed (36% of linolenic acid in the diet). In our case a 4% supplement was effective in modifying the lipid composition of the carcass and yielded values similar to those stated above.

Dietary fatty acids were more readily deposited in adipose tissue than in muscle. Moreover, backfat showed the greatest susceptibility to change in composition. Thus, compared to longissimus muscle, subcutaneous adipose tissue had nearly 2% higher contents ($P < 0.001$) of C18:3*n*−3, C18:1*n*−9c, and C18:1*n*−9t in pigs fed L, O, and H, respectively. Larick et al. (1992) also observed changes in fatty acid composition that were more pronounced in backfat than in muscle tissues.

The percentage of MUFA in the backfat ($P < 0.001$) was 25% higher in animals fed O than in animals fed H and 39% higher than in animals fed L. Others, using other fat sources (St. John et al., 1987; Miller et al., 1990) or ingredients rich in oleic acid (Myer et al., 1992), have observed that the animal tissues increase in monounsaturation, due to the increase in C18:1*n*−9c.

Animals fed H had the highest percentage ($P < 0.001$) of TFA, 16 times higher than in animals fed O or L. This greater concentration was due to the concentration of elaidic acid ($P < 0.001$), the major trans fatty acid in the diet (and represents 88% of TFA in the diet); however, higher levels were also observed ($P < 0.001$) for the other trans fatty acids analyzed: C16:1*n*−7t and the trans isomers of the acid C18:2*n*−6. The level of TFA in the tissues was lower than of its cis MUFA isomers despite the fact that diet H contained similar quantities of each. This likely occurred because the sources of C18:1*n*−9c can be both the diet or *de novo* synthesis, whereas for C18:1*n*−9t the only source is the diet. Digestion and absorption of cis and trans fatty acids in humans are similar, and no differences have been observed in levels in blood (Adolf and Emken, 1986).

The higher levels of TFA observed in adipose tissues (backfat and abdominal fat) in comparison with muscle tissues (longissimus and trapezius) could be due to the fact that pigs were fed with high-energy diets and stored the excess of fatty acids esterified to glycerol in adipocytes, whereas in muscle most fatty acids are associated with membrane phospholipids. According to Beare-Rogers (1983), TFAs are mainly incorporated in the triglycerides. The turnover rates of membrane fatty acids and uptake of the excess energy by adipocytes are factors responsible for the differential fatty acid composition of both tissues.

The maximum TFA values obtained in our study (ca. 4% in muscle and 6% in adipose tissue) are higher than usual in meat and other pork products (lower than 0.8%; Dickey, 1995; Fernández, 1996) and similar to those in beef meat (between 2.5% and 7%; Wolff, 1995). Research on pigs fed diets with 20% added fat and 39% TFA has yielded 13% TFA in adipose tissue (Royce et al., 1984). High TFA contents in tissues of pigs fed

Table 6. Fatty Acid Composition of Abdominal Fat from Pigs Fed Diets Containing Pomace Oil (O), Hydrogenated Oil (H), and Linseed Oil (L)[a]

fatty acids (%)	treatment			SE	P
	O	H	L		
C10:0	0.09	0.11	0.09	0.008	0.088
C12:0	0.09	0.09	0.08	0.005	0.196
C14:0	1.34[ab]	1.44[b]	1.19[a]	0.055	0.010
C15:0	0.05	0.05	0.05	0.008	0.986
C16:0	24.16[a]	23.57[a]	21.84[b]	0.423	0.003
C16:1*n*−7t	0.04[a]	0.18[b]	0.03[a]	0.005	0.001
C16:1*n*−9	0.35[a]	0.35[a]	0.22[b]	0.013	0.001
C16:1*n*−7	1.70	1.90	1.72	0.095	0.245
C17:0	0.26[ab]	0.28[a]	0.22[b]	0.017	0.046
C18:0	13.26	13.82	12.68	0.501	0.246
C18:1*n*−9t	0.28[a]	5.09[b]	0.33[a]	0.155	0.001
C18:1*n*−9	43.55[a]	35.97[b]	34.62[b]	0.617	0.001
C18:1*n*−7	2.01[a]	2.45[b]	1.97[a]	0.096	0.003
C18:2*n*−6t	0.08[a]	0.50[b]	0.10[a]	0.013	0.001
C18:2*n*−6	9.77[a]	10.64[ab]	11.29[b]	0.391	0.039
C20:0	0.20	0.22	0.22	0.016	0.779
C18:3*n*−6	0.03[a]	0.03[a]	0.18[b]	0.007	0.001
C20:1*n*−9	0.85[a]	0.61[b]	0.64[b]	0.039	0.001
C18:3*n*−3	0.83[a]	1.57[a]	9.97[b]	0.300	0.001
C20:2*n*−6	0.46	0.44	0.49	0.031	0.429
C20:3*n*−6	0.07	0.07	0.07	0.005	0.584
C20:3*n*−3	0.13[a]	0.21[a]	1.31[b]	0.048	0.001
C20:4*n*−6	0.19[a]	0.18[a]	0.14[b]	0.009	0.007
C20:5*n*−3	0.03[a]	0.03[a]	0.10[b]	0.005	0.001
C22:4*n*−6	0.07[ab]	0.08[b]	0.06[a]	0.007	0.022
C22:5*n*−3	0.08[a]	0.12[b]	0.34[c]	0.013	0.001
C22:6*n*−3	0.05	0.04	0.06	0.007	0.104
SFA	39.45[a]	39.55[a]	36.35[b]	0.748	0.008
MUFA	48.46[a]	41.28[b]	39.18[c]	0.671	0.001
PUFA	11.70[a]	13.40[a]	24.03[b]	0.655	0.001
TFA	0.39[a]	5.77[b]	0.45[a]	0.168	0.001
n−3	1.12[a]	1.97[a]	11.79[b]	0.302	0.001
n−6	10.59[a]	11.43[ab]	12.24[b]	0.420	0.037
PUFA/SFA	0.30[a]	0.34[a]	0.66[b]	0.024	0.001
n−6/*n*−3	9.54[a]	6.19[b]	1.04[c]	0.420	0.001

[a] SE, standard error. Means in the same row that do not have a common superscript (a−c)are different ($P < 0.05$).

Table 7. Fatty Acid Composition of Backfat from Pigs Fed Diets Containing Pomace Oil (O), Hydrogenated Oil (H), and Linseed Oil (L)[a]

fatty acids (%)	treatment			SE	P
	O	H	L		
C10:0	0.07[ab]	0.09[a]	0.06[b]	0.009	0.042
C12:0	0.07	0.07	0.06	0.004	0.180
C14:0	1.11[ab]	1.22[a]	0.98[b]	0.049	0.007
C15:0	0.05	0.05	0.04	0.004	0.067
C16:0	21.41	22.01	20.50	0.527	0.120
C16:1*n*−7t	0.04[a]	0.20[b]	0.03[a]	0.009	0.001
C16:1*n*−9	0.41[a]	0.36[a]	0.23[b]	0.017	0.001
C16:1*n*−7	1.50[a]	1.49[a]	1.25[b]	0.072	0.035
C17:0	0.29	0.29	0.24	0.020	0.108
C18:0	11.38[a]	14.27[b]	13.20[ab]	0.651	0.018
C18:1*n*−9t	0.29[a]	5.88[b]	0.32[a]	0.101	0.001
C18:1*n*−9	47.08[a]	36.47[b]	33.47[c]	0.547	0.001
C18:1*n*−7	1.99[a]	2.24[b]	1.66[c]	0.074	0.001
C18:2*n*−6t	0.07[a]	0.60[b]	0.07[a]	0.016	0.001
C18:2*n*−6	10.88[a]	10.97[a]	12.45[b]	0.416	0.020
C20:0	0.22	0.26	0.24	0.013	0.071
C18:3*n*−6	0.03[a]	0.03[a]	0.21[b]	0.006	0.001
C20:1*n*−9	0.94[a]	0.68[b]	0.67[b]	0.041	0.001
C18:3*n*−3	0.96[a]	1.56[a]	11.36[b]	0.227	0.001
C20:2*n*−6	0.57	0.54	0.62	0.024	0.053
C20:3*n*−6	0.08	0.07	0.07	0.005	0.565
C20:3*n*−3	0.17[a]	0.25[a]	1.60[b]	0.036	0.001
C20:4*n*−6	0.20[a]	0.15[b]	0.12[b]	0.013	0.002
C20:5*n*−3	0.01[a]	0.02[a]	0.11[b]	0.004	0.001
C22:4*n*−6	0.08[a]	0.08[a]	0.05[b]	0.007	0.014
C22:5*n*−3	0.09[a]	0.11[a]	0.35[b]	0.010	0.001
C22:6*n*−3	0.04	0.04	0.05	0.004	0.122
SFA	34.59[a]	38.27[b]	35.32[a]	1.050	0.044
MUFA	51.91[a]	41.24[b]	37.28[c]	0.607	0.001
PUFA	13.10[a]	13.80[a]	26.99[b]	0.612	0.001
TFA	0.39[a]	6.68[b]	0.41[a]	0.117	0.001
n−3	1.27[a]	1.97[a]	13.46[b]	0.225	0.001
n−6	11.83[a]	11.84[a]	13.53[b]	0.449	0.017
PUFA/SFA	0.38[a]	0.37[a]	0.77[b]	0.031	0.001
n−6/*n*−3	9.34[a]	6.31[b]	1.00[c]	0.407	0.001

[a] SE, standard error. Means in the same row that do not have a common superscript (a−c) are different ($P < 0.05$).

hydrogenated fats could have different repercussions in the population, depending on (a) actual TFA intake—for instance, in Spain the average is 2.4 g/person/day (Boatella et al., 1993), whereas in Scotland it is 6.5g/person/day (Bolton-Smith et al., 1995), and (b) the usual consumption of meat and pork products. Although a recent expert panel report (International Life Science Institute, 1995) states that there is not enough epidemiological evidence to establish maximum TFA dietary thresholds, some researchers (Katan, 1995; Willet and Ascherio, 1995) point to nonnegligible effects which call for a certain control on TFA contents in food.

Animals fed diet H had the highest percentages ($P < 0.05$) of SFA. Babatunde et al. (1968) observed an increase in saturated fatty acid levels in the adipose tissue of animals fed a diet supplemented with 3% hydrogenated coconut oil.

Backfat PUFA levels were highest in pigs fed L (ca. 2 times as much as in pigs fed O or H). The differences ($P < 0.001$) were due to the higher levels of fatty acids of the *n*−3 series and specifically in 18:3*n*−3 contents were 7 times higher than in pigs fed H and 12 times higher than in pigs fed O. Other authors using different levels of linseed that allowed levels of C18:3*n*−3 in the diet of 26−27% have observed levels of C18:3*n*−3 of 5.80% in adipose tissue (Cunnane et al., 1990), 5.90% in longissimus muscle, and 8.90% in subcutaneous backfat (Cherian and Sim, 1995). These figures are lower than those in our study (abdominal fat, 9.97%; backfat, 11.36%; longissimus muscle, 9.04%), which could be due to the different levels of absorption in the small intestine of the acid C18:3*n*−3 depending on the source of *n*−3 in the diet, seed, or linseed oil. Possibly, the digestion and absorption of linolenic acid from seed is less efficient than from oil, since the latter has higher levels of triglycerides, the absorption of which is greater than 95% (Nelson and Ackman, 1988).

Greater percentages ($P < 0.001$) in C20:5*n*−3 (EPA) and C22:5*n*−3 were observed in all tissues of animals fed diet L compared with those fed O and H. At the same time, animals fed L showed a lower percentage ($P < 0.05$) of arachidonic acid (C20:4*n*−6).

Others who used linseed products as *n*−3 fatty acid sources have reported similar results. Cherian and Sim (1995) and Romans et al. (1995) observed a significant increase in the percentage of C20:5*n*−3 and C22:5*n*−3 in the backfat but not in C22:6*n*−3. According to Voss et al. (1991) the step from C22:5*n*−3 to C22:6*n*−3 is not produced directly by Δ^4 desaturase without the prior reactions of elongation, desaturation, and shortening. Possibly the lack of increase in the percentage of C22:6*n*−3 was due to the existence of a more complex metabolic route for its formation. The lower levels ($P < 0.05$) of arachidonic and docosatetraenoic acids observed in this study suggest that competition in the synthesis of *n*−6 and *n*−3 derivatives by their precursors, C18:2*n*−6 and C18:3*n*−3, respectively, occurred. Fatty acids of both the *n*−6 and *n*−3 families share the enzyme for the synthesis of their derivatives. Specifically, the enzyme Δ^6 desaturase is responsible for the

Table 8. Cholesterol Content of Muscular Tissues from Pigs Fed Diets Containing Pomace Oil (O), Hydrogenated Oil (H), and Linseed Oil (L)[a]

	cholesterol (mg/100 g of wet tissue)
tissues	
m.longissimus	48.35
m.trapezius	60.56
P	0.001
SE	0.89
treatment	
O	52.64
H	55.76
L	54.97
P	0.128
SE	1.12
tissue treatment P	0.098

[a] SE, standard error.

synthesis of the *n*−6 derivative, arachidonic acid, and the *n*−3 derivative, eicosapentaenoic acid. The increase in levels of linolenic acid could displace the activity of the enzyme toward the synthesis of its derivative, with the consequent reduction in the levels of arachidonic acid. The same could occur in the step from C20:5*n*−3 to C22:5*n*−3, which would be further favored over the step from C20:4*n*−6 to C22:4*n*−6.

Although there are studies that show the beneficial effects of using diets rich in EPA and DHA, other aspects that are no less important must also be borne in mind, such as the *n*−6/*n*−3 modification in the diet. Using diets rich in C18:3*n*−3 has been shown to be effective ($P < 0.001$) in modifying the *n*−6/*n*−3 balance (L 1.00 vs O 9.34 and H 6.31). This balance was greater than that reported by Otten et al. (1988) using a diet supplemented with 5% fish oil (*n*−6/*n*−3 1.64).

In our study, samples from pigs fed L had 23−27% PUFA, the relationship PUFA/SFA was 0.7, and the *n*−6/*n*−3 ratio was 1.1, a noticeable improvement in the quality of lipid composition when compared with data from the composition tables (8−10% PUFA, PUFA/SFA 0.2−0.3, and *n*−6/*n*−3 8−15; Pennington, 1994).

Cholesterol. Longissimus muscle showed a lower level of cholesterol ($P < 0.001$) than the trapezius muscle. Busboom et al. (1991) observed no differences between perirenal fat, subcutaneous fat, and longissimus muscle, but they did find a difference in intramuscular fat (67.50, 64.50, and 58.60 vs 106.80 mg of cholesterol/100 g of tissue, respectively). They consider the higher level of cholesterol in intramuscular fat to be due to the fact that the adipose cells are smaller and contain a higher proportion of cellular membrane, which is where the cholesterol is mainly to be found, in comparison with the adipose cells of backfat and abdominal fat. The higher level of cholesterol ($P < 0.001$) found in the trapezius muscle may be related to the higher level of intramuscular fat in this tissue in comparison with the longissimus muscle.

No effect of type of dietary fat on cholesterol was observed in muscle (Table 8). The effect of manipulating the dietary lipid composition on the cholesterol content of pork tissues is controversial. Leszcynsky et al. (1992) observed increases in muscle cholesterol concentration by feeding diets rich in PUFA. In contrast, Bohac and Rhee (1988) observed no differences by feeding pigs diets with increasing levels of MUFA. According to Harris et al. (1993), the liver plays an important role as a modulator of the cholesterol concentration in the serum, and the cholesterol content in tissues, as a fundamental component of cell membranes, tends to remain constant. These could be explanations for the lack of any observed difference between the experimental diets in our experimental conditions.

IMPLICATIONS

The results of this study demonstrate the possibility of improving TFA and PUFA levels in muscle and adipose tissues of pigs. As for TFAs, although there are no official guidelines on limiting the amount in the diet, their possible negative effects on human health remain controversial. On the other hand, using linseed or similar sources of PUFA, especially from the *n*−3 series, in pigs' diets, leads to an improvement in the nutritive value of the lipid composition.

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