Effects of modified tall oil versus a commercial source of conjugated linoleic acid and increasing levels of modified tall oil on growth performance and carcass characteristics of growing-finishing pigs[1,2]

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ABSTRACT: Two experiments were conducted to evaluate the effects of conjugated linoleic acid (CLA)-enriched feed additives for swine. These additives included a source of CLA that was commercially available (CLA-60) and modified tall oil (MTO). Experiment 1 used 36 barrows (initially 37.6 ± 2.8 kg) to compare the effects of CLA-60 and MTO on growth performance and carcass characteristics of finishing pigs. The corn-soybean meal diets contained .50% soybean oil (control), .50% CLA-60, or .50% MTO. Pigs fed CLA-60 had less (P = .03) ADG from 37.6 to 72.6 kg than the control pigs; otherwise, pigs fed either CLA-60 or MTO had growth performance similar (P > .15) to that of the control pigs. Pigs fed MTO grew faster (P = .03) and consumed more feed (P = .10) over the duration of the experiment (37.6 to 106.4 kg) than pigs fed CLA-60. Dietary treatment did not affect (P > .15) plasma triglycerides or carcass characteristics, but pigs fed either MTO or CLA-60 had greater saturation of fatty acids in the adipose tissue at the 10th rib than pigs fed the control diet. Experiment 2 used 80 barrows (initially 33.4 ± 2.2 kg) to examine the effects of increasing levels of MTO on growth performance and carcass characteristics of finishing pigs. The corn-soybean meal diet contained 1% cornstarch, which was replaced with MTO to give dietary levels of .25, .50, or 1.00% MTO. Dietary treatment did not affect (P > .15) growth performance. Feeding increasing levels of MTO quadratically decreased (P = .02) average backfat thickness and longissimus muscle drip loss (P = .04) and quadratically increased longissimus muscle area (P = .07) and percentage lean (P = .03). Feeding MTO tended to increase belly firmness (P < .10) compared with pigs fed the control diet. These traits appeared to be optimized with .50% MTO. In summary, pigs fed MTO had greater ADG, ADFI, and ending BW than pigs fed CLA-60. Feeding MTO does not appear to affect growth performance but improves carcass lean content and may additionally improve some aspects of meat quality in growing-finishing pigs.

Key Words: Carcasses, Growth, Linoleic Acid, Tall Oil

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Introduction

Conjugated linoleic acid (**CLA**) was positively identified by Ha et al. (1987) and is an imprecise collective term describing the positional and geometric isomers of octadecadienoic acid (C18:2). Contrary to the methylene-interrupted double bonds of octadecadienoic acid, the double bonds in CLA are separated by a single carbon-carbon bond, and these bonds can occur at multiple locations along the carbon chain. Conjugated linoleic acid is known to elicit many favorable biological responses, including: 1) increased rate and efficiency of gain in growing rats (Chin et al., 1994) and swine (Dugan et al., 1997; Thiel et al., 1998; Ostrowska et al., 1999); 2) reduced fat deposition and increased lean in mice (Park et al., 1997) and swine (Dugan et al., 1997; Thiel et al., 1998; Ostrowska et al., 1999); 3) improved immune function in rats and chicks (Cook et al., 1993; Sugano et al., 1998); and 4) reduced atherosclerosis in rabbits (Lee et al., 1994) and hamsters (Nicolosi et al., 1997). It is also a potent in vivo and in vitro anticarcinogen (Ha et al., 1990; Ip et al., 1991; Durgam and Fernandes, 1997).

Tall oil is the nonaqueous layer of rosin acids and fatty acids produced during the kraft (sulfate) paper

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process. Modified tall oil (**MTO**) contains high levels of CLA and results from further processing of the fatty acid portion of tall oil (Figure 1). It has been evaluated only recently in swine diets (O'Quinn et al., 1999b,c; Woodworth et al., 1999; O'Quinn et al., 2000) but has intrinsic properties (Tables 1 and 2) that lend itself to a comparison with the commercially available Tonalin CLA 60 product (**CLA-60**). Therefore, the objectives of this study were to compare the effects of CLA-60 and MTO as CLA-enriched feed additives and to determine the effects of increasing levels of MTO on growth performance and carcass characteristics of growing-finishing pigs.

Materials and Methods

General

Pigs used in both experiments were terminal offspring of PIC L326 or 327 boars × C22 sows (PIC, Franklin, KY). Experimental procedures were approved by the Kansas State University Institutional Animal Care and Use Committee (Protocol No. 1416). The CLA-60 and MTO were analyzed for fatty acid profiles (Tables 1 and 2) using the boron triflouride method (AOAC, 1995) and a Hewlett-Packard gas chromatograph (Hewlett-Packard, Co., 5890 Series II Gas Chromatograph, Palo Alto, CA) equipped with a flame ionization detector and a Supelco SP-2560 fused silica capillary column (100 m × .25 mm i.d. × .20 μm film thickness; Supelco, Inc., Bellefonte, PA) designed to elute fatty acids in the range of 14 to 20 carbons, including conjugated isomers of linoleic acid. Helium was used as the carrier gas and hexane as the solvent. The flame ionization detector was run by hydrogen and compressed air. Flow rate was 1 mL/min, and the oven temperature program consisted of holding the temperature at 170°C for 10 min, followed by an increase to 230°C at 1°C/min and a final hold at 230°C for 5 min. The detector and injector temperatures were 280 and 250°C, respectively, and the sample injection was splitless. Column performance and detector responses were verified using commercially available fatty acid (Supelco, Inc.) and CLA (Sigma Chemical, St. Louis, MO) standards. The same batch of MTO was

Table 1. Specifications for soybean oil, modified tall oil (MTO), and commercially available conjugated linoleic acid (CLA)[a]

Item	Soybean oil[b]	MTO	Tonalin CLA 60[c]
Unsaponifiables, % maximum	1.5	2.8	1.0
Iodine value	130	162	139
Specific gravity	.92	.91	.92
Acid value, mg KOH/g	192	195	199
Fatty acid composition, %			
Conjugated linoleic acid	—	69	58.4
Total linoleic acid	50.65	78	64.9
Oleic acid	21.41	22	22.7
Saturated fatty acids	20.50	<1	12.3

[a]Values for MTO and Tonalin CLA 60, excluding the fatty acid profiles, which were analyzed, are guaranteed analyses from the manufacturers.
[b]Soybean oil values (Bailey, 1951), excluding the fatty acid profiles, which were analyzed, provided as a reference.
[c]Provided by PharmaNutrients, Inc. (Lake Bluff, IL).

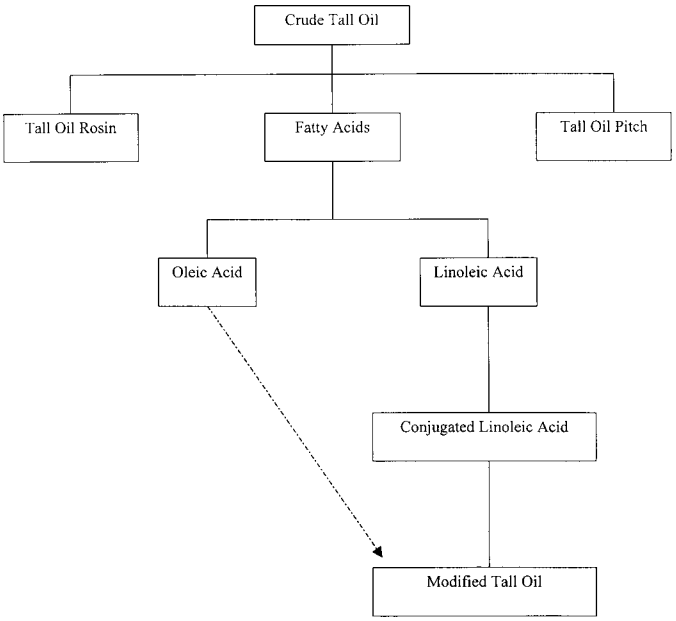

Figure 1. Crude tall oil distribution. The dotted line from oleic acid to modified tall oil indicates a blended final product.

Table 2. Analyzed chemical composition of modified tall oil (MTO) and commercially available conjugated linoleic acid (CLA)

Fatty acid, % of sample	Soybean oil[a]	MTO	Tonalin CLA 60
14:0	.43	—	—
16:0	15.96	.46	7.65
16:1	—	—	—
18:0	4.11	.07	5.15
18:1[b]	21.41	19.84	24.73
18:2	50.65	2.29	4.81
18:3	6.38	—	—
20:1	1.06	—	—
Conjugated linoleic acid (18:2)			
*c*9, *t*11	—	20.52	21.33
*t*9, *t*11	—	14.80	3.90
*c*10, *c*12	—	13.98	10.38
*t*10, *c*12	—	14.37	16.40
3 unidentified CLA isomers	—	8.83	3.79
Total CLA	—	72.50	55.80
Unidentified lipids	—	4.83	1.85
Total	100.00	100.00	100.00

[a]Analyzed soybean oil values provided as a reference.
[b]Includes oleic acid and less than 2% elaidic acid.

Table 3. Percentage composition of control diets (as-fed basis)

	Exp. 1		Exp. 2	
Ingredient	Grower[a]	Finisher[b]	Grower[a]	Finisher[b]
Corn	69.29	78.63	68.76	78.08
Soybean meal (46.5% CP)	27.47	18.39	27.50	18.43
Limestone	1.06	.89	1.05	.88
Cornstarch[c]	—	—	1.00	1.00
Monocalcium phosphate	.85	.76	.86	.78
Soybean oil[d]	.50	.50	—	—
Salt	.35	.35	.35	.35
Vitamin premix[e]	.20	.20	.20	.20
Trace mineral premix[f]	.15	.15	.15	.15
Antibiotic[g]	.13	.13	.13	.13
Analyzed CP, %[h]	18.60	15.69	18.07	14.98

[a]Grower diets were fed from 37.6 to 72.6 kg BW (Exp. 1) or 33.4 to 72.6 kg BW (Exp. 2) and were formulated to contain 1.00% lysine, .65% Ca, and .55% total P.
[b]Finisher diets were fed from 72.6 to 106.4 kg BW (Exp. 1) or 72.6 to 118.7 kg BW (Exp. 2) and were formulated to contain .75% lysine, .55% Ca, and .50% total P.
[c]The MTO replaced cornstarch on an equal weight basis to give the four dietary treatments in Exp. 2. of 0, .25, .50, or 1.00% MTO.
[d]Modified tall oil and CLA-60 replaced soybean oil on an equal weight basis to give the three dietary treatments in Exp. 1 of .50% soybean oil, .50% CLA-60, or .50% MTO.
[e]Provided per kg of complete diet: vitamin A, 8,818 IU; vitamin D_3, 1,322 IU; vitamin E, 35.27 IU; menadione (menadione dimethylpyrimidinol bisulphite), 3.52 mg; vitamin B_{12}, .03 mg; riboflavin, 7.94 mg; pantothenic acid, 26.46 mg; and niacin, 44.10 mg.
[f]Provided per kg of complete diet: Zn (from zinc oxide), 165.3 mg; Fe (from ferrous sulfate), 165.3 mg; Mn (from manganese oxide), 39.7 mg; Cu (from copper sulfate), 16.5 mg; I (from calcium iodate), .3 mg; and Se (from sodium selenite), .3 mg.
[g]Provided 110 mg/kg tylosin.
[h]Values represent the average of all diets within each growth period.

used for both Exp. 1 and 2. The source of CLA-60 used in Exp. 1 (Tonalin CLA 60) was a commercially available product that had been further processed from sunflower oil. Diets (Table 3) for both experiments were formulated to be nutritionally adequate (NRC, 1988), maintained accepted amino acid ratios (Baker, 1995) relative to lysine, and were analyzed for CP (AOAC, 1995).

Experiment 1

Thirty-six crossbred barrows (initially 37.6 ± 2.8 kg BW) were used to evaluate the effects of MTO and CLA-60 on growth performance and carcass characteristics of growing-finishing pigs. Pigs were blocked on the basis of initial weight and ancestry in a randomized complete block design and allotted randomly to one of three dietary treatments with six replicate pens per treatment and two pigs per pen.

Diets were fed in meal form in two phases (37.6 to 72.6 and 72.6 to 106.4 kg BW). Modified tall oil and CLA-60 were substituted on an equal weight basis for soybean oil in the experimental diets. The level of CLA-60 used in this study (.50%) was chosen because it was commonly used in experiments with growing rats (Chin et al., 1994; Belury and Kempa-Steczko, 1997; Pariza et al., 1997; Park et al., 1997; Park et al., 1999) and pigs (Thiel et al., 1998).

Pigs were housed in an environmentally controlled finishing barn with two pigs in each 1.33- × 1.33-m totally slatted-floored pen. They were allowed ad libitum access to feed and water through one single-hole self-feeder and a nipple waterer, respectively. Pigs were weighed every 14 d to determine ADG, ADFI, and gain-to-feed ratio (**G/F**). The day before slaughter, plasma blood samples were collected (via vena cava puncture) from each pig following 3 h of feed removal and stored frozen (–11.5°C) until analyzed. Plasma triglyceride levels were determined enzymatically using a commercially available diagnostic kit (Sigma Chemical).

Pigs were slaughtered at the Kansas State University abattoir when their average weight reached 106.4 ± 7.1 kg. Carcass measurements (backfat thickness, longissimus muscle area, and cold carcass weights); visual evaluation of the longissimus muscle for color, marbling, and firmness (NPPC, 1991); and Minolta color spectrophotometry (L*, a*, and b*; CIE, 1976) were obtained for each pig at 24 h postmortem. Visual evaluation and color spectrophotometry of the longissimus muscle were conducted following a 30-min bloom. Drip loss (modified from Kauffman et al., 1986) was determined at 48 h postmortem. For the drip loss determination, a 2.54-cm cube from the center of the longissimus muscle (10th rib) was suspended in a sealed, air-filled container and stored at 4°C for 24 h. Thus, the cubes were standardized for size but not weight, and drip loss was measured as a weight loss percentage. Color spectrophotometry measurements (three surface readings per longissimus muscle) were determined with a Minolta Chroma Meter Model CR-200 using illuminant C (Minolta Co., Ltd., Osaka, Ja-

pan). Additionally, a section of adipose tissue (backfat) collected at the 10th rib of each pig was stored frozen until analyzed. Fatty acid analyses (duplicate sample readings from each pig) of backfat were conducted using the methods of Sukhija and Palmquist (1988) and a Hewlett-Packard 5730A Gas Chromatograph (Hewlett-Packard, Co., Avondale, PA) equipped with a 3.2-mm i.d. 12-m glass column packed with 10% SP-1200/1% H_3PO_4 on 80/100 Chromosorb W AW (Supelco, Inc.). Nitrogen was used as the carrier gas and benzene as the solvent. The flame ionization detector was run by hydrogen and compressed air. Flow rate was 60 mL/min, and the oven temperature was raised from 120 to 220°C at 8°C/min during the 15-min analysis of each sample. Column performance and detector response was verified using commercially available fatty acid standards (rapeseed, RM-5, and RM-6 standards; Matreya, Inc., Pleasant Gap, PA).

Data were analyzed as a randomized complete block with pen as the experimental unit. Planned nonorthogonal contrasts were used to compare the three dietary treatments. Hot carcass weight was used as a covariate in the statistical analyses of all carcass data. All analyses were performed using the GLM procedure of SAS (1988).

Experiment 2

Eighty crossbred barrows (initially 33.4 ± 2.2 kg BW) were used to evaluate effects of increasing levels of dietary MTO on growth performance and carcass characteristics of growing-finishing pigs. This experiment was conducted due to observed differences in growth performance between pigs fed CLA-60 and MTO, and visual improvements in carcass characteristics of pigs fed either CLA-60 or MTO in Exp. 1. Pigs were blocked on the basis of initial weight and ancestry and allotted randomly to one of four dietary treatments with 10 replicate pens per treatment and two pigs per pen.

All diets were steam-conditioned at 75°C for 10 s and then pelleted through a 4.8-mm die. Although fatty acid profiles were not determined after pelleting, this level and duration of heating should have had minimal impact on MTO because MTO is extremely heat stable. The Gardner color number for MTO changes from 2^+ to 3^+ after heating at 205°C for 24 h, as tested according to the standard method for measuring color after heating of tall oil fatty acids (ASTM, 1995). Before pelleting, the corn was ground to an average particle size of 935 μ, as analyzed by methods of ASAE (1983). Average percentage fines and pellet durability index (ASAE, 1987) for all diets were 11.98 and 78.70%, respectively. Diets were fed in two phases (33.4 to 72.6 and 72.6 to 118.7 kg BW; Table 3), and MTO was substituted on an equal weight basis for cornstarch in the experimental diets to achieve levels of .25, .50, or 1.00% MTO.

Pigs were housed, weighed, and bled as described for Exp. 1. They were slaughtered when their average weight reached 118.7 ± 7.6 kg. Carcass analyses were as described for Exp. 1 except during fabrication of the carcasses (24 h postmortem), when the bellies from the right sides of all carcasses were removed and used for firmness determinations. An initial firmness determination was made immediately after the spareribs were removed, and again at 1 and 5 min later. Firmness was defined as the distance measured from end to end of the belly when it was suspended centrally from a horizontal bar with the skin laid dorsally in orientation. Thus, larger values indicate firmer bellies.

Data were analyzed as a randomized complete block. Pen was the experimental unit for all calculations. The IML procedure of SAS (1988) was used to generate the necessary orthogonal polynomial contrast coefficients needed for the GLM procedures of SAS (1988) to evaluate the linear and quadratic effects of increasing MTO. Thus, despite unequally spaced treatments, all data were analyzed using GLM procedures. Hot carcass weight was used as a covariate for the carcass analysis, and belly weights and lengths were used as covariates in the analysis of belly firmness. Additionally, a single degree of freedom contrast was used to compare the belly firmness of pigs fed the control diet with the average of pigs fed diets supplemented with MTO.

Results

Experiment 1

From 37.6 to 72.6 kg BW, pigs fed CLA-60 had lesser ($P = .03$) ADG than pigs fed the control diet (Table 4). All other growth performance results for pigs fed either CLA-60 or MTO were similar ($P > .15$) to those for the pigs fed the control diet. However, the initial reduction in ADG for pigs fed CLA-60 compared with pigs fed the control diet led to a tendency ($P = .09$) for a reduction in BW for pigs fed CLA-60 throughout the study. Pigs fed MTO had higher ADG during the growing ($P < .01$) and finishing ($P = .10$) phases and overall ($P = .03$) than pigs fed CLA-60; this was attributable to numerical improvements in ADFI and G/F during the growing period and to higher ADFI during the finishing ($P = .06$) and overall ($P = .10$) for pigs fed MTO. In agreement, pigs fed MTO had heavier ($P = .01$) ending BW than pigs fed CLA-60. Using the growth model supplied by the NRC (1998) for high lean-gain pigs, it was determined that the differential responses in ADG between pigs fed diets containing CLA-60 and MTO was not due solely to the observed differences in ADFI between the two groups. This indicates that CLA-60 and MTO possibly are acting via different modes within the body.

Dietary treatment did not affect ($P > .15$) carcass characteristics or plasma triglyceride level (Table 5). Adipose tissue from pigs fed diets containing either CLA-60 or MTO was more ($P < .01$) saturated than adipose tissue from pigs fed the control diet (Table 6). The differences in saturation were primarily due to

Table 4. Growth performance of barrows fed modified tall oil (MTO) or commercially available conjugated linoleic acid (CLA; Exp. 1)[a]

Item	Control (1)	MTO (2)	CLA-60[b] (3)	SEM	Probability 1 vs 2	Probability 1 vs 3	Probability 2 vs 3
Initial BW, kg	37.8	37.6	37.6	.134	.34	.19	.70
37.6 to 72.6 kg BW							
ADG, kg	1.04	1.07	.98	.018	.35	.03	<.01
ADFI, kg	2.62	2.63	2.53	.060	.93	.28	.25
G/F	.40	.41	.39	.052	.49	.43	.15
72.6 to 106.4 kg BW							
ADG, kg	1.03	1.08	.96	.047	.44	.35	.10
ADFI, kg	3.24	3.38	3.05	.118	.41	.27	.06
G/F	.32	.32	.31	.097	.79	.80	.61
37.6 to 106.4 kg BW							
ADG, kg	1.03	1.07	.97	.014	.39	.17	.03
ADFI, kg	2.92	2.99	2.78	.086	.56	.27	.10
G/F	.35	.36	.35	.059	.64	.62	.34
Final BW, kg	106.7	109.4	102.2	1.696	.29	.09	.01

[a]Values are means for six replicate pens per treatment and two pigs per pen.
[b]Tonalin CLA 60.

Table 5. Carcass characteristics of barrows fed modified tall oil (MTO) or commercially available conjugated linoleic acid (CLA; Exp. 1)[abc]

Item	Control (1)	MTO (2)	CLA-60[d] (3)	SEM	Probability 1 vs 2	Probability 1 vs 3	Probability 2 vs 3
Shrink loss, %	2.12	2.18	2.17	.076	.55	.47	.77
Backfat, cm							
First rib	3.68	3.43	3.48	.132	.21	.38	.93
Tenth rib	2.34	2.21	2.21	.155	.57	.34	.59
Last rib	1.96	1.83	1.83	.082	.31	.68	.71
Last lumbar	1.96	1.96	1.80	.090	.99	.83	.82
Average[e]	2.49	2.36	2.36	.071	.24	.36	.98
Dressing percentage	72.65	72.32	71.61	.386	.57	.61	.93
Lean percentage[f]	50.95	51.35	51.15	.971	.77	.34	.45
Longissimus muscle							
Area, cm^2	36.65	36.58	35.16	.446	.97	.23	.22
Visual color[g]	2.65	2.50	2.60	.077	.20	.39	.90
Marbling[g]	2.48	2.83	2.82	.211	.27	.26	.76
Firmness[g]	3.18	3.07	3.15	.278	.78	.65	.51
L*[h]	50.93	52.70	52.66	1.306	.53	.65	.47
a*[h]	10.80	11.00	12.01	1.175	.93	.99	.96
b*[h]	7.00	7.57	7.89	.895	.76	.82	.71
Hue angle[h]	43.86	48.60	44.92	1.840	.27	.79	.37
Saturation index[h]	13.11	13.36	14.39	1.268	.93	.64	.71
a*\b*[h]	1.55	1.45	1.53	.045	.33	.79	.45
Drip loss, %	3.03	2.98	2.83	.517	.93	.21	.23
Triglycerides, mg/dL	33.33	40.17	41.17	4.615	.32	.26	.88

[a]Values are means for six replicate pens per treatment and two pigs per pen.
[b]Hot carcass weight was used as a covariate in the statistical analysis.
[c]Carcass length (mean = 81.23 cm) and visual muscle score (mean = 2.53) were not affected ($P > .15$) by dietary treatment.
[d]Tonalin CLA 60.
[e]Average backfat is the average of the first and last rib and last lumbar fat depths.
[f]Lean percentage was derived from NPPC (1991) equations with 5% fat in the carcass.
[g]Scoring system of 1 to 5: 2 = grayish pink, traces to slight, or soft and watery; 3 = reddish pink, small to modest, or slightly firm and moist; and 4 = purplish red, moderate to slightly abundant, or firm and moderately dry for color, marbling, and firmness, respectively.
[h]Means were derived from three sample readings per loin. Measures are dark to light (L*), redness (a*), yellowness (b*), red to orange (hue angle), or vividness or intensity (saturation index).

Table 6. Percentage fatty acid composition of subcutaneous adipose tissue of barrows fed modified tall oil (MTO) or commercially available conjugated linoleic acid (CLA; Exp. 1)[a,b]

Item	Control (1)	MTO (2)	CLA-60[c] (3)	SEM	Probability 1 vs 2	Probability 1 vs 3	Probability 2 vs 3
8:0	.06	.07	.09	.015	.75	.18	.30
10:0	.07	.09	.06	.010	.37	.23	.05
12:0	.07	.12	.13	.006	<.01	<.01	.29
14:0	1.36	2.14	2.31	.062	<.01	<.01	.07
16:0	24.63	28.88	28.99	.480	<.01	<.01	.88
16:1	4.34	5.97	5.86	.309	<.01	<.01	.80
18:0	11.05	13.19	13.45	.397	<.01	<.01	.65
18:1	38.55	32.19	30.82	.317	<.01	<.01	<.01
18:2	14.84	11.81	12.42	.520	<.01	<.01	.42
18:3	2.18	1.76	1.72	.112	.02	.01	.82
20:0	1.01	1.66	1.64	.160	.01	.01	.92
20:1	ND[d]	.51	.98	.111	<.01	<.01	<.01
22:0	1.02	1.01	.96	.063	.88	.51	.61
22:1	.65	.55	.52	.046	.14	.07	.68
24:0	.17	.05	.05	.039	.04	.05	.91
Saturated fat	39.44	47.21	47.70	.595	<.01	<.01	.58
Unsaturated fat	60.56	52.79	52.32	.595	<.01	<.01	.58
Ratio[e]	.65	.90	.91	.020	<.01	<.01	.53

[a]Values are means for duplicate readings of backfat for six replicate pens per treatment and two pigs per pen.
[b]Analyses were conducted on fatty acid methyl esters (FAME). For example, 18:2 refers to methyl linoleate.
[c]Tonalin CLA 60.
[d]Not detectable.
[e]Refers to the ratio of saturated to unsaturated fat.

more ($P \leq .01$) palmitic (16:0) and stearic (18:0) acids and less ($P \leq .01$) oleic (18:1) and linoleic (18:2) acids for pigs fed diets containing either MTO or CLA-60 than for pigs fed the control diet. Few differences in adipose fatty acid profiles were observed between pigs fed diets containing either CLA-60 or MTO. Pigs fed MTO had more ($P \leq .05$) capric (10:0) and oleic (18:1) acids but less ($P \leq .07$) myristic (14:0) and eicosanoic (20:1) acids than pigs fed CLA-60. However, the absolute differences in these fatty acids were quite small.

Experiment 2

Feeding increasing levels of MTO did not affect ($P > .15$) ADG, ADFI, or G/F during either growth period or when determined over the entire experiment (Table 7). These results agree with those of Exp. 1, in which MTO also did not affect growth performance.

Increasing levels of MTO quadratically reduced 10th rib, last rib, last lumbar, and average backfat thicknesses ($P < .05$; Table 8) and quadratically increased longissimus muscle area ($P = .07$). Taken together, the reductions in backfat and increases in longissimus muscle area yielded a quadratic increase in lean percentage ($P = .03$) from feeding increasing levels of MTO. These quadratic responses were a result of little or no improvement from feeding more than .50% MTO. Increasing levels of MTO quadratically decreased ($P = .04$) longissimus muscle drip loss percentage. The increasing levels of MTO linearly decreased ($P \leq .07$) a* and b* values. Thus, the longissimus muscle from pigs fed MTO was less red but also less yellow. Color intensity (saturation index) of the longissimus muscle was linearly and quadratically ($P \leq .09$) reduced by feeding increasing levels of MTO. Belly firmness was neither linearly nor quadratically affected ($P > .20$) by dietary treatment, but the average belly firmness measured at 0, 1, or 5 min after suspension from pigs fed diets containing MTO was greater ($P < .10$) than that of bellies from pigs fed the control diet. Other carcass characteristics including visual color, firmness, and marbling of the longissimus muscle; dressing percentage; and plasma triglycerides were not affected ($P > .10$) by feeding increasing levels of MTO.

Discussion

Confusion still abounds as to the biologically active isomer(s) contained in CLA (Kramer et al., 1998). The *cis* 9, *trans* 11 isomer initially was proposed as the active one based on its predominance in milk, dairy products, and meats. New evidence suggests that the *trans* 10, *cis* 12 isomer may be the isomer responsible for reductions in fat (Park et al., 1999). However, in our experiments we have fed only mixed CLA isomers and, as such, cannot attribute biological activity to any single isomer. Both the MTO and CLA-60 diets were similar in their concentrations of these two isomers; however, growth performance was significantly different between the two diets. Several reasons may exist

for these observed differences: 1) the different isomeric profiles of the two compounds, 2) the large amount of saturated fatty acids present in CLA-60, 3) the larger relative concentration of actual CLA present in MTO (about 15% more), 4) an isomer in higher concentration in MTO (i.e., *trans* 9, *trans* 11), 5) a combination of the above reasons, or 6) an interaction(s) of the above reasons.

A difference in total CLA content between CLA-60 and MTO probably is not the cause of the varying biological responses to the two products. Diets in Exp. 1 were not balanced for CLA content, but instead for the oil mix containing the products, and the difference in dietary CLA content (.2790 vs .3625% for CLA-60 and MTO, respectively) was appreciable. However, the data from Exp. 2, using a .25% MTO inclusion (.1813% dietary CLA), did not demonstrate a decline in performance, and growth performance was not affected by a 1% MTO inclusion (.7250% CLA). These results indicate that the observed differences in growth performance from feeding CLA-60 and MTO must have been due to some other factor(s).

Feeding CLA has been shown to improve percentage lean and feed utilization in rodents (Chin et al., 1994; Park et al., 1997; Cook and Pariza, 1998) and pigs (Dugan et al., 1997; Thiel et al., 1998; Ostrowska et al., 1999). Other reports with rodents have shown that CLA actually may reduce lean percentage (West et al., 1998) and growth rate (Belury and Kempa-Steczko, 1997; West et al., 1998). Reduced ADFI has been reported consistently for both swine (Dugan et al., 1997) and rodents fed CLA (Park et al., 1997; West et al., 1998). However, this response has been ruled out as the predominant factor behind the ability of CLA to reduce adiposity (Park et al., 1997; West et al., 1998). The latter authors speculated that CLA might invoke palatability or postingestive effects that lead to a food aversion or that modulate appetite without adversely affecting the animal. The possible modulation of appetite could be related to the ability of CLA to alter energy metabolism (West et al., 1998). Recently, CLA was shown to dose-dependently activate the *peroxisome proliferator-activated receptor-*γ reporter gene (Houseknecht et al., 1998b), which partially controls transcription of the leptin gene (Houseknecht et al., 1998a). Thus, the reduced feed intakes associated with CLA may be related to an increased leptin expression elicited by CLA itself. However, the unique CLA isomer profile of MTO may not affect leptin expression, as evidenced by the growth performance differences in Exp. 1.

The increased saturation of fat observed in Exp. 1 for both CLA-60 and MTO was similar to that reported by Eggert et al. (1999) for CLA, which they identified as the reason for increased belly firmness from feeding CLA to pigs. Feeding either CLA-60 or MTO decreased oleic acid (the predominant fatty acid in pork fat) content by nearly 20%. The reduction of unsaturated fats by feeding MTO or CLA-60 increases belly firmness by increasing the melting point of the fat. Though MTO and CLA-60 are composed primarily of CLA, the total linoleic acid content of the adipose tissue was decreased by feeding either compound. The reductions in linoleic and oleic acids and increases in palmitic and stearic acids observed herein support the hypothesis that CLA increases belly firmness by increased fat saturation (Eggert et al., 1999). If alterations similar to those observed in the fatty acid profiles of adipose tissue occur in the muscle, then either MTO or CLA-60 could be used to improve the fatty acid profile of pork by increasing the stearic acid content and possibly making the meat less susceptible to oxidation. The incorporation of CLA into the adipose tissue was not determined in the present studies, and, as such, no inferences can be made regarding potential differences between the tissue incorporation of CLA-60 and MTO

Table 7. Growth performance of barrows fed increasing modified tall oil (Exp. 2)[a]

	Modified tall oil, %					Probability	
Item	0	.25	.50	1.00	SEM	Linear	Quadratic
Initial BW, kg	33.4	33.5	33.4	33.3	.055	.18	.60
33.4 to 72.6 kg BW							
ADG, kg	1.08	1.07	1.09	1.07	.023	.77	.73
ADFI, kg	2.37	2.32	2.31	2.35	.043	.40	.51
G/F	.45	.46	.47	.45	.033	.57	.21
72.6 to 118.7 kg BW							
ADG, kg	.98	.98	.99	.97	.024	.85	.89
ADFI, kg	2.99	2.96	2.96	2.86	.061	.93	.43
G/F	.33	.33	.33	.34	.057	.70	.29
33.4 to 118.7 kg BW							
ADG, kg	1.03	1.01	1.03	1.01	.019	.71	.79
ADFI, kg	2.71	2.67	2.67	2.63	.048	.79	.44
G/F	.38	.38	.39	.38	.038	.88	.19
Final BW, kg	119.1	118.0	119.6	117.8	1.497	.65	.73

[a]Values are means for 10 replicate pens per treatment and two pigs per pen.

Table 8. Carcass and longissimus muscle characteristics of barrows fed increasing modified tall oil (Exp. 2)[a,b]

	Modified tall oil, %					Probability	
Item	0	.25	.50	1.00	SEM	Linear	Quadratic
Shrink loss, %	1.99	2.03	2.03	2.09	.033	.71	.20
Backfat, cm							
First rib	3.84	3.86	3.66	3.73	.103	.74	.13
Tenth rib	2.24	2.11	1.93	1.96	.112	.82	.04
Last rib	2.44	2.51	2.31	2.31	.072	.19	.04
Last lumbar	2.16	2.03	1.93	1.88	.031	.75	.02
Average[c]	2.79	2.79	2.64	2.64	.067	.60	.02
Lean percentage[d]	51.79	52.52	53.59	53.69	.617	.83	.03
Dressing percentage	74.29	73.63	73.69	73.31	.253	.27	.11
Longissimus muscle							
Area, cm^2	41.23	42.00	43.42	43.48	.395	.80	.07
Visual color[e]	2.35	2.53	2.35	2.39	.087	.19	.49
Marbling[e]	2.18	2.38	2.30	2.39	.097	.30	.41
Firmness[e]	2.40	2.65	2.63	2.64	.104	.21	.27
L*[f]	55.08	53.78	53.49	55.03	.825	.22	.52
a*[f]	13.95	12.25	11.92	13.27	.555	.04	.12
b*[f]	12.13	8.47	8.27	9.50	1.203	.07	.14
Hue angle[f]	48.05	48.37	48.11	50.41	1.964	.87	.75
Saturation index[f]	19.21	14.91	14.53	16.34	1.252	.04	.09
a*\b*[f]	1.39	1.46	1.47	1.41	.032	.16	.40
Drip loss, %	5.17	4.99	3.60	4.95	.482	.64	.04
Belly firmness, cm[g]							
Initial[h]	23.47	28.07	27.64	30.28	2.343	.39	.23
1 min[h]	21.84	26.16	25.70	28.35	2.195	.39	.22
5 min[h]	20.45	24.64	22.89	25.63	2.213	.36	.53
Triglycerides, mg/dL	29.50	28.12	31.36	30.42	2.349	.64	.39

[a]Values are means for 10 replicate pens per treatment and two pigs per pen.
[b]Hot carcass weight was used as a covariate in the analysis of carcass data.
[c]Average backfat is the average of the first and last rib and last lumbar fat depths.
[d]Lean percentage was derived from NPPC (1991) equations with 5% fat in the carcass.
[e]Scoring system of 1 to 5: 2 = grayish pink, traces to slight, or soft and watery; 3 = reddish pink, small to modest, or slightly firm and moist; and 4 = purplish red, moderate to slightly abundant, or firm and moderately dry for color, marbling, and firmness, respectively.
[f]Means were derived from three sample readings per loin. Measures are dark to light (L*), redness (a*), yellowness (b*), red to orange (hue angle), or vividness or intensity (saturation index).
[g]Belly weights and lengths were used as covariates in the analysis of belly firmness.
[h]The average belly firmness of pigs fed MTO was greater ($P < .10$) than the average belly firmness of pigs fed the control diet. Contrasted values were initial, 23.47 vs 28.66; 1 min, 21.84 vs 26.74; and 5 min, 20.45 vs 24.39, for pigs fed the control diet or MTO-supplemented diets, respectively.

in growing-finishing swine. Li and Watkins (1998) also observed an increase in total saturated fatty acids in rats fed CLA and suggested that CLA inhibited Δ9-desaturase activity. This could explain the observed fatty acid profiles in Exp. 1 and why the tissue fatty acids of pigs fed MTO and CLA-60 are not modeled after dietary fatty acids.

It should be noted that the pigs in Exp. 2 were started at a lighter BW and were on experimental feed longer than the pigs in Exp. 1. Consequently, these pigs were about 12 kg heavier at the conclusion of the study. The duration of the study and(or) the heavier ending body weights may have contributed to the decreased backfat from feeding MTO observed in Exp. 2, but not in Exp. 1. Although an increase in longissimus muscle area contributed to an increase in percentage lean in Exp. 2, the key determinant to carcass leanness from feeding MTO was the reduction in backfat. The mode of action whereby CLA reduces adiposity is still not understood fully. Pariza et al. (1997) reported that the feeding of CLA elicited an enhanced norepinephrine-induced lipolysis and hormone-sensitive lipase activity and increased total carnitine palmitoyltransferase activity. Park et al. (1997) also reported that CLA reduced lipoprotein lipase activity, while enhancing lipolysis, and stimulated fatty acid β-oxidation in skeletal muscle and fat pad, but not liver. Satory and Smith (1999) suggested that CLA decreases body fat accumulation by reducing preadipocyte number when given during a period(s) of hyperplastic growth. Satory and Smith (1999) observed increased adipocyte size and lipid content in response to CLA. The use of differing methodologies, CLA sources and levels, animal models, duration of feeding, and other factors also create confusion. The lipid filling noted by Satory and Smith (1999) and increased saturation of fat observed

in Exp. 1 and also by Eggert et al. (1999) provide possible explanations for the improvements in belly firmness noted from feeding CLA (Thiel et al., 1998; Eggert et al., 1999) and MTO (O'Quinn et al., 1999b,c; Woodworth et al., 1999).

Dugan et al. (1999) fed 2% CLA to finishing pigs and evaluated meat quality. They observed an increase in intramuscular marbling (subjective scores and solvent-extracted intramuscular fat), but CLA did not affect other measured parameters, including shear force or drip loss percentage. O'Quinn et al. (2000) also observed increases in subjective marbling scores from feeding MTO. Further evaluation of the effects that economical levels of CLA have on meat quality measures is warranted. Conjugated linoleic acid is reported to exhibit some antioxidant properties (Decker, 1995; Haumann, 1996), though this is disputed (van den Berg et al., 1995). The increased intramuscular fat from feeding CLA would be an advantage, as long as the fat did not oxidize during display. The decrease in b* values from feeding MTO in Exp. 2 suggests that MTO exhibited antioxidant properties that stabilized the intramuscular fat, thereby reducing the incidence of off-colors. Additionally, the saturating effects of MTO leave less opportunity for free radical formation in the muscle. Feeding MTO in conjunction with vitamin E has been shown to improve display color stability in pork (Waylan et al., 1999), and MTO preferentially shifted the deposition of α-tocopherol to the adipose tissues in rats (O'Quinn et al., 1999a).

Concern over the unsaponifiable fraction of MTO probably is not warranted, as was the concern over tall oil fatty acids (AAFCO, 1985). Modified tall oil is processed further from tall oil fatty acids, and the oleic acid portion of tall oil fatty acids is currently used in the food industry. The vast majority of the unsaponifiables in tall oil are plant sterols, with sitosterol being the largest single component (Conner and Rowe, 1975). Recent research (Jones et al., 1998) has successfully demonstrated a use for tall oil phytosterols in treating human patients with hypercholesterolemia.

Modified tall oil, if approved for use as a feed additive, offers a means of improving carcass leanness and potentially some aspects of meat quality in growing-finishing pigs.

Implications

Feeding a commercially available source of conjugated linoleic acid resulted in decreased average daily gain and average daily feed intake compared with feeding modified tall oil. Feeding modified tall oil decreased backfat and increased percentage lean and belly firmness. The improvement in belly firmness probably was due to an increased saturation of the fatty acids present in pork fat. Because differences exist in the biological potency of compounds containing conjugated linoleic acid, clearer terminology needs to be adopted that removes confusion over the composition of the conjugated linoleic acid-enriched product. From a practical standpoint, .50% appears to be the optimal dietary inclusion level of modified tall oil to improve carcass characteristics in growing-finishing pigs.

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