Effects of dietary additions of modified tall oil, chromium nicotinate, and L-carnitine on growth performance, carcass characteristics, and bacon characteristics of growing-finishing pigs

A. T. Waylan, P. R. O'Quinn[1], R. D. Goodband, J. A. Unruh[2], J. L. Nelssen, J. C. Woodworth, and M. D. Tokach

Department of Animal Sciences and Industry, Kansas State University, Manhattan, KS, USA 66506.
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Waylan, A. T., O'Quinn, P. R., Goodband, R. D., Unruh, J. A., Nelssen, J. L., Woodworth, J. C. and Tokach, M. D. 2003. **Effects of dietary additions of modified tall oil, chromium nicotinate, and L-carnitine on growth performance, carcass characteristics, and bacon characteristics of growing-finishing pigs**. Can. J. Anim. Sci. **83**: 459–467. Eighty gilts were supplemented with modified tall oil (MTO), chromium nicotinate (CrNic), and L-carnitine to determine effects on growth and meat quality characteristics. Pigs were assigned to one of eight treatments in a $2 \times 2 \times 2$ factorial with main effects of MTO (0 or 0.5%), CrNic (0 or 50 μg kg^{-1}), and L-carnitine (0 or 50 mg kg^{-1}). Pigs fed MTO had increased ($P = 0.03$) average daily gain and pigs fed CrNic had improved ($P = 0.02$) gain:feed. Bellies from pigs supplemented with MTO with no CrNic were firmer ($P < 0.05$) than bellies from all other treatment combinations. No differences ($P > 0.05$) were detected for longissimus muscle (LM) visual or objective color values. Furthermore, no differences ($P > 0.05$) were detected for LM Warner-Bratzler shear force or sensory traits. Bacon from pigs fed MTO had firmer ($P < 0.05$) slices than bacon from pigs fed no MTO. These data suggest improvements in growth performance from addition of 0.50% MTO and(or) 50 μg kg^{-1} CrNic to diets of finishing gilts. Supplementing with MTO, CrNic, and L-carnitine had minimal effects on carcass, LM color and sensory, or bacon characteristics.

Key words: Pork, modified tall oil, chromium nicotinate, L-carnitine, longissimus muscle, bacon

Waylan, A. T., O'Quinn, P. R., Goodband, R. D., Unruh, J. A., Nelssen, J. L., Woodworth, J. C. et Tokach, M. D. 2003. **Incidence de l'addition de tallöl modifié, de nicotinate de chrome et de L-carnitine aux aliments sur la croissance des porcs d'élevage, les caractéristiques de la carcasse et celles du bacon**. Can. J. Anim. Sci. **83**: 459–467. Quatre-vingts truies nullipares ont reçu un supplément de tallöl modifié (TM), de nicotinate de chrome (NicCr) et de L-carnitine, l'idée étant de vérifier l'incidence de ces additifs sur la croissance des animaux et la qualité de la viande. Les animaux ont été répartis entre huit traitements selon une grille factorielle $2 \times 2 \times 2$ pour déterminer les principaux effets du TM (0 ou 5 %), du NicCr (0 ou 50 mg kg^{-1}) et de la L-carnitine (0 ou 50 μg kg^{-1}). Les porcs recevant du TM ont enregistré un gain quotidien moyen plus élevé ($P = 0{,}03$) tandis que ceux recevant du NicCr présentaient un meilleur rapport gain:aliments ($P = 0{,}02$). Les flancs des animaux nourris de TM sans NicCr étaient plus fermes ($P < 0{,}05$) que ceux des animaux des autres combinaisons. Les attributs visuels et la valeur objective de la couleur du longissimus n'ont subi aucune variation ($P > 0{,}05$). On n'a pas non plus relevé de variation ($P > 0{,}05$) pour la force de cisaillement Warner-Bratzler et les propriétés organoleptiques du muscle. Le bacon des animaux nourris de TM donnait des tranches plus fermes ($P < 0{,}05$) que celui des animaux qui n'en avaient pas reçu. Les données laissent croire que l'addition de 0,50 % de TM ou de 50 μg de NicCr par kg, ou les deux, au régime des truies nullipares de finition conduit à une meilleure croissance. L'addition d'un supplément de TM, de NicCr et de L-carnitine a une incidence minime sur la carcasse, la couleur et les propriétés organoleptiques du longissimus et les propriétés du bacon.

Mots clés: Porc, tallöl modifié, nicotinate de chrome, L-carnitine, longissimus, bacon

Pigs fed modified tall oil (MTO, a compound high in conjugated linoleic acid, CLA), chromium nicotinate (CrNic), and L-carnitine singularly have improved growth performance and carcass composition. Pigs fed MTO had improved average daily gain (ADG) compared to controls (Waylan et al. 2002). Additional benefits of supplementing swine diets with MTO are decreased average backfat and increased lean percentage (O'Quinn et al. 1998). Unruh et al. (2000) summarized several studies and concluded feeding 0.5% MTO decreased average backfat 4%, increased longissimus area 3%, and increased belly firmness 15% in pork carcasses. Metabolic effects of CLA (Park et al. 1997; O'Quinn et al. 2000) include increased serum insulin concentrations, increased saturation of subcutaneous fat, reduced lipoprotein lipase activity, and stimulated fatty acid β-oxidation.

Chromium is an essential trace element for normal metabolism of carbohydrates, proteins, and lipids in human and animal systems (Offenbacher and Pi-Sunyer 1988; Mertz 1993). In swine, chromium picolinate (CrPic) has been reported to

[1]*Present address: Prestage Farms, Inc., Clinton, NC, USA 28329*
[2]*To whom correspondence should be addressed.(e-mail: junruh@oznet.ksu.edu).*

Abbreviations: **ADG**, average daily gain; **ADFI**, average daily feed intake; **CrNic**, chromium nicotinate; **CrPic**, chromium picolinate; **CLA**, conjugated linoleic acid; **G/F**, gain:feed; **LM**, longissimus muscle; **MTO**, modified tall oil; **WBSF**, Warner-Bratzler shear force

improve ADG (Mooney and Cromwell 1995), gain:feed (G:F) (Lindemann et al. 1995), and muscling with decreased fat deposition (Page et al. 1993; Smith et al. 1994; Mooney and Cromwell 1995). Researchers (Evock-Clover et al. 1993; White et al. 1993) have indicated that feeder pigs fed CrPic had decreased serum insulin and glucose concentrations because it was believed that chromium may work as a cofactor with insulin. The increased insulin receptor sensitivity and increased protein synthesis in muscle may to some extent explain the mechanism of the observed increased muscling and reduced lipogenesis in swine supplemented with chromium.

Carnitine is a vitamin-like compound that facilitates transport of long-chain fatty acids into the mitochondria for adenosine triphosphate production via β-oxidation and oxidative phosphorylation (Owen et al. 1996). Smith et al. (1994) reported that finishing pigs (34 to 102 kg) fed carnitine had larger LM area and greater percentage muscle than control pigs, but growth performance was not affected. Owen et al. (1996) also concluded dietary L-carnitine reduces lipid accretion in early-weaned pigs. Owen et al. (2001a) explained the mechanism for these improved carcass characteristics. The accelerated β-oxidation should increase metabolite flow through pyruvate carboxylase. Furthermore, activation of pyruvate carboxylase favors gluconeogenesis and the use of carbon chains of pyruvate for the production of amino acids. Also, enhanced fatty acid oxidation reduces the oxidation of branched-chain amino acids.

Supplementing swine diets with MTO, CrNic, or L-carnitine fed singularly has decreased fatness and increased muscle accumulation by different proposed mechanisms. Feeding these supplements simultaneously may result in an additive effect of more efficiently partitioning nutrients toward lean deposition and away from fat accumulation. Additionally, MTO may improve belly quality by increased saturation of fatty acids. However, little is known about the effects of CrNic, L-carnitine, or the combination of these compounds on loin and belly quality attributes. Therefore, this experiment was undertaken to determine the effect of feeding MTO, CrNic, and L-carnitine to pigs during the growing-finishing period on growth, carcass traits, and pork quality characteristics.

MATERIALS AND METHODS

Animals and Diets

Pigs used in this experiment were terminal offspring of PIC L326 or 327 boars × C22 sows (PIC, Franklin, KY, USA). Experimental procedures were approved by the Kansas State University Institutional Animal Care and Use Committee (Protocol No. 1525). The CrNic (14.0% chromium and 84.1% nicotinic acid) and L-carnitine (49.2% carnitine) were provided by Lonza, Inc., Fair Lawn, NJ, USA. The MTO was provided by Hercules, Inc., Wilmington, DE, USA. The fatty acid profile of the MTO used in this experiment was determined using methods described by O'Quinn et al. (2000). The MTO used in this experiment contained 1.20% palmitic acid, 1.14% palmitoleic acid, 25.68% oleic acid, 4.58% α-linoleic acid, and 67.40% CLA. The CLA fraction was also separated into its *cis* (*c*) and *trans* (*t*) isomers. This CLA fraction comprised 30.88% *c*9, *t*11; 15.65% *t*9, *t*11; 15.34% *c*10, *c*12; 24.87% *t*10, *c*12; and 13.26% unidentified CLA isomers.

Table 1. Percentage composition of control diets (as-fed basis)

Ingredient (%)	IFN	Grower[z]	Finisher[y]
Corn	4-02-935	66.50	76.93
Soybean meal (46.5% CP)	5-04-612	27.70	18.53
Soybean oil[x]	4-07-983	3.00	2.00
Limestone	6-02-632	1.04	0.88
Monocalcium phosphate	6-26-334	0.88	0.78
Salt	6-04-152	0.35	0.35
Vitamin premix[w]	–	0.25	0.25
Trace mineral premix[v]	–	0.15	0.15
Antibiotic[u]	–	0.13	0.13
Analyzed CP[t]	–	18.41	16.00

[z]Diets were fed from 45.4 to 72.6 kg BW and were formulated to contain 1.00% lysine, 0.65% Ca, and 0.55% total P.
[y]Diets were fed from 72.6 to 106.6 kg BW and were formulated to contain 0.75% lysine, 0.55% Ca, and 0.50% total P.
[x]Modified tall oil was substituted for an equal weight of soybean oil; chromium nicotinate and L-carnitine were mixed into the complete diet to give the additional dietary treatments.
[w]Provided per kg of complete diet: vitamin A, 8818 IU; vitamin D_3, 1322 IU; vitamin E, 35.27 IU; menadione (menadione dimethylpyrimidinol bisulphite), 3.52 mg; vitamin B_{12}, 0.03 mg; riboflavin, 7.94 mg; pantothenic acid, 26.46 mg; and niacin, 44.10 mg.
[v]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), 0.3 mg; and Se (from sodium selenite), 0.3 mg.
[u]Provided 110 mg kg^{-1} tylosin.
[t]Values represent the average of all diets within each growth period.

Eighty crossbred gilts (initially 45.4 kg) were used. Pigs were blocked on the basis of initial weight and ancestry in a randomized complete block design and allotted randomly to one of eight dietary treatments arranged as a $2 \times 2 \times 2$ factorial with five replicate pens of two pigs per treatment. Main effects included MTO (0 or 0.50%), CrNic (0 or 50 μg kg^{-1}), and L-carnitine (0 or 50 mg kg^{-1}).

Diets were formulated to meet or exceed suggested requirement estimates for pigs of this weight (National Research Council 1998) and maintained accepted amino acid ratios (Baker 1995) relative to lysine. Diets were fed in meal form in two phases (45.4 to 72.6 and 72.6 to 106.6 kg body weight; Table 1). Modified tall oil was substituted on an equal weight basis for soybean oil, and CrNic and L-carnitine were added to the complete diet to achieve the additional dietary treatments. All diets were analyzed for crude protein (Association of Official Analytical Chemists 1995). Dietary inclusion of 0.50% MTO was chosen because O'Quinn et al. (2000) found it was the optimal level that reduced backfat, increased LM area, improved color characteristics, and decreased drip loss. The inclusion of 50 μg kg^{-1} for CrNic was selected because Page et al. (1993) and O'Quinn et al. (1998) found it was the optimal level to increase ADG. The 50 mg kg^{-1} of L-carnitine was selected as the optimal level to provide the maximum response of improved ADG and G:F in grower pigs (Smith

et al. 1994) and increased LM area and reduced backfat (Owen et al. 1994).

Pigs were housed in an environmentally controlled finishing barn with two pigs in each 1.33-m × 1.33-m totally slatted-floored pen. Pigs were allowed ad libitum access to feed and water through one single-hole self-feeder and a nipple waterer, respectively. Pigs and feeders were weighed every 14 d to determine ADG, average daily feed intake (ADFI), and G:F.

Slaughter and Fabrication

When the average weight of the pigs reached 106.6 kg, feed was removed approximately 12 h prior to slaughter and pigs (n = 80) were transported to the Kansas State University abattoir. Pigs were slaughtered humanely using standard industry procedures approved by the Kansas State University Animal Care and Use Committee. At approximately 45 min postmortem, carcasses were chilled at –2°C and sprayed with chilled water (2°C) for 10 s every 10 min during the first 10 h of chilling. At 26 h postmortem, carcasses were weighed and midline backfat thickness was measured opposite the first rib, last rib, and last lumbar vertebra to determine average backfat. Carcasses were then ribbed between the 10th and 11th ribs, and 10th rib fat depth was measured over the LM at 3/4 the distal distance from the backbone. The loins and bellies were then removed for further analyses. Longissimus muscle measurements consisted of LM area and visual analyses at the 10th rib for color, firmness, and marbling [National Pork Producers Council (NPPC) 1991]. Objective colors (L^*, a^*, and b^*; Commission Internationale de l'Eclairage 1976) of the LM and subcutaneous fat were also obtained. Color measurements (two surface readings per LM or subcutaneous fat sample) were determined using a Hunter Lab MiniScanXE Model 45/OLAV with Illuminant C, a 10° observer, and a 2.54-cm-diameter aperture (Hunter Associates Laboratory, Inc., Reston, VA). Lean percentage was derived from NPPC (1991) equations with 5% fat in the carcass. Drip loss [modified from Kauffman et al. (1986)] was determined at 48 h postmortem. After the spareribs were removed, belly weight and length were recorded, and belly firmness was determined by centrally suspending the bellies over a horizontal bar with the skin laid in a dorsal orientation and measuring the distance from end to end initially and at 5 min.

From each wholesale loin, a 23-cm long boneless sample was removed posterior to the 10th rib, weighed, vacuum packaged, and aged for an additional 6 d at 1°C. At 7 d postmortem, the boneless loins were removed from vacuum packages and weighed. Loin purge loss was calculated by 100 × (initial loin weight – loin weight after removal from the package) / initial loin weight. The pH was determined with a probe (Toa, Ltd., Tokyo, Japan) at the anterior end of the boneless loin. At approximately the last rib, 2.54-cm-thick chops were cut, anterior to posterior, for sensory panel and Warner-Bratzler shear force (WBSF) analyses. Sensory panel and WBSF chops were crust frozen for 30 min at –40°C, individually vacuum packaged, and stored at -40°C until analysis.

Longissimus Muscle

Shear Force Determination

The LM chops for WBSF were thawed at 2°C for 24 h in the vacuum bag with the seal broken. Chops were weighed and cooked to an internal temperature of 71°C in a Blodgett dual-air-flow oven (DFG-201, G.S. Blodgett Co., Inc., Burlington, VT, USA). Internal temperature was monitored with thermocouples attached to a DORIC Minitrend 205 temperature monitor (Emerson Electric S. A., Doric Div., San Diego, CA, USA). Chops were cooled at room temperature (21°C) for 1 h, reweighed, and subsequently chilled for 24 h at 2°C. Then six 1.27-cm-diameter cores were removed parallel to the muscle fibers and sheared perpendicular to the muscle fibers using a WBSF attachment on an Instron Universal Testing Machine (Model 4201 Instron, Canton, MA, USA). A 50-kg compression load cell was used at a crosshead speed of 250 mm min^{-1}. The six values were averaged per sample to determine a WBSF value for statistical analysis. Thawing loss and cooking loss percentages were calculated by 100 × (initial chop weight – thawed chop weight)/initial chop weight and 100 × (thawed chop weight – cooked chop weight)/thawed chop weight, respectively.

Sensory Evaluation

The LM chops were thawed at 2°C for 24 h in the vacuum bag with the seal broken. The chops were cooked as previously described for WBSF to an internal temperature of 71°C. Chops were removed from the oven and immediately cut into cubes of 1.27 cm × 1.27 cm × cooked chop thickness. Cubes were kept warm in enamel-coated double-broiler pans. A trained [American Meat Science Association (AMSA) 1995] seven-member descriptive attribute sensory analysis panel received two samples from each chop. Samples were evaluated warm by panelists in an environmentally controlled (21 ± 1°C, 55 ± 5% relative humidity) room partitioned into booths with a combination of red and green light (< 107.64 lumens). Six sensory traits of myofibrillar tenderness, connective tissue amount, overall tenderness, juiciness, flavor intensity, and off-flavor were all evaluated on eight-point scales to the nearest 0.5. Myofibrillar tenderness and overall tenderness were evaluated on a scale from 1 = extremely tough to 8 = extremely tender. Connective tissue was ranked on a scale from 1 = abundant to 8 = none. Juiciness was scored on a scale from 1 = extremely dry to 8 = extremely juicy. Flavor intensity was evaluated on a scale from 1 = extremely bland to 8 = extremely intense. Off-flavor intensity was ranked from 1 = extremely intense to 8 = none.

Bacon Manufacture

Bellies were thawed at 3°C for 72 h in their vacuum bags. The bellies were weighed, injected with pickle (10% of weight) using a multineedle pump injector (Formaco FGM 20/40, Food Machinery Co., A/S, Copenhagen K, Denmark), and reweighed. The pickle was a standard curing mixture (13.2% salt, 7% sugar, 1.0% sodium nitrite, 2% maple sugar, and 76.8% water). Bellies were tumbled (VT85, FPEC Corp., Santa Fe Springs, CA, USA) for 4 h, weighed, and hung on trees before cooking in a smokehouse

(D7752 Mauer Inc., Reichenau, West Germany). After attaining an average internal temperature of 64°C (approximately 2 h) bellies completed a drying cycle (1.25 h) with temperatures starting at 54°C and ending at 60°C. The smoking cycle followed for 1.5 h at 60°C with smoke (100% hickory wood sawdust). After processing to an internal temperature of 57°C, bellies were placed in a 3°C cooler for 40 h and reweighed.

Cured bellies were cut into 4-mm-thick bacon slices (Berkel 919/1, Berkel Inc., LaPorte, IN, USA). Twelve slices at approximately one-third the length of the bacon slab from the cranial end (American Meat Science Association 1985) were obtained for analysis. Firmness of the bacon slices was evaluated visually on a scale of 1 = very soft and oily and 8 = very brittle and crumbly. A score of 5 was considered optimal for bacon firmness. Number and size of holes within the bacon slices were ranked on a composite subjective evaluation scale of 1 = very high number of holes and 8 = no holes. The depth of the sixth bacon slice removed was measured to determine cured belly thickness. Eight slices were vacuum packaged, stored at 3°C for 4 d, and then used for sensory evaluation.

Sensory Evaluation

Bacon slices were removed from their vacuum bag and cooked for 5 min on each side in the Blodgett dual-air-flow oven set at 176°C. Cooked bacon slices were cut into 2.54-cm × 2.54-cm subsamples (pieces). A trained (AMSA 1995) 12-member qualitative descriptive analysis panel evaluated two pieces/sample. Eight samples (one from each treatment) per session were evaluated warm in an environmentally controlled (21 ± 1°C, 55 ± 5% relative humidity) room partitioned into booths with a combination of red and green light (< 107.64 lumens). Five sensory traits: brittleness, flavor intensity, saltiness, aftertaste, and off-flavor were all evaluated on eight-point scales to the nearest 0.5. Brittleness was evaluated on a scale from 1 = soft to 8 = extremely crispy. Flavor intensity was ranked on a scale from 1 = extremely bland to 8 = extremely intense. Saltiness was scored on a scale from 1 = extremely unsalty to 8 = extremely salty. Aftertaste was scored on a scale from 1 = none to 8 = extremely intense. Off-flavor intensity was ranked from 1 = extremely intense to 8 = none.

Statistical Analyses

Data were analyzed as a randomized complete block design with dietary treatments arranged as a 2 × 2 × 2 factorial with main effects of MTO (0 or 0.50%), CrNic (0 or 50 mg kg^{-1}), and L-carnitine (0 or 50 μg kg^{-1}). Initial weight and ancestry were used to establish blocks. Statistical analyses for growth, carcass, LM characteristics, and bacon measurements were performed with the GLM procedure of SAS software (SAS Institute Inc., 1998) using the pen mean as the experimental unit. The statistical model included main effects and interactions of the main effects. Hot carcass weight was used as a covariate in the statistical analyses of all quantitative carcass data except belly firmness, in which belly weight and length were the covariates. All interaction means were separated using the least significant difference procedure when the respective *F*-tests were significant ($P < 0.05$).

RESULTS

Growth Performance

No interactions ($P > 0.17$) of MTO, CrNic, and L-carnitine were observed for growth performance traits (Table 2). Pigs fed MTO had greater ADG ($P = 0.03$; 0.98 vs. 0.94 kg d^{-1}, respectively) and tended to have higher ADFI ($P = 0.10$; 2.45 vs. 2.53, respectively). Pigs fed CrNic had greater G:F ($P = 0.02$) than pigs fed no CrNic (0.39 vs. 0.37, respectively). The addition of L-carnitine did not affect ($P > 0.41$) growth performance.

Carcass Characteristics

Carcass characteristics measured at 26 h postmortem (dressing percentage, average backfat thickness, LM area, and calculated percentage lean) were not affected ($P > 0.12$) by dietary treatments (Table 2). An interaction of CrNic and MTO was observed ($P = 0.04$) for belly firmness. Bellies from pigs supplemented with MTO without CrNic were firmer ($P < 0.05$) at initial measurement time and after 5 min than bellies from pigs fed MTO with CrNic and pigs fed no MTO with or without CrNic. However, pigs fed MTO with CrNic were only firmer ($P < 0.05$) than pigs fed no MTO and no CrNic. When averaged across the two time intervals, pigs fed MTO had a 26.0% increase in belly firmness compared to pigs fed diets not containing MTO.

Dietary treatment combination did not affect ($P > 0.10$) LM quality measurements taken at 26 h postmortem including drip loss percentage, visual color, marbling, firmness or color spectrophotometry (Table 3). Additionally, feeding MTO, CrNic, and L-carnitine did not affect ($P > 0.07$) any color measurements of the subcutaneous fat taken at the 10th rib.

Longissimus Muscle

Loin Storage

Feeding MTO, CrNic, and L-carnitine did not affect ($P > 0.13$) pH values at 7 d postmortem (Table 4). An MTO × L-carnitine interaction ($P = 0.02$) was observed for loin purge loss. Boneless loins from pigs fed no MTO with no L-carnitine (1.86%) had less ($P < 0.05$) purge loss than loins from pigs fed MTO with no L-carnitine (2.56%). Purge losses of loins from pigs fed MTO with L-carnitine (1.97%) and no MTO with L-carnitine (2.46%) were intermediate but similar ($P > 0.05$) to those in the other interaction treatments.

Warner–Bratzler Shear Force and Sensory Evaluation

No differences were detected among treatments ($P > 0.07$) for percentages of thawing and cooking losses or WBSF values (Table 4). The LM connective tissue amount, juiciness, flavor intensity, and off-flavor attributes were similar ($P > 0.09$) among treatments. Myofibrillar (6.18 vs. 5.86) and overall tenderness (6.25 vs. 5.92) scores for chops from pigs fed no MTO were higher ($P < 0.05$; more tender) than comparable sensory scores from pigs fed MTO.

Table 2. Influence of modified tall oil (MTO), chromium nicotinate (CrNic), and (or) L-carnitine on growth performance and carcass characteristics[z,y]

	MTO (%)												
	0	0	0	0	0.50	0.50	0.50	0.50					
	CrNic (μg kg^{-1})												
	0	50	0	50	0	50	0	50					
	L-carnitine (mg kg^{-1})									Probability			
Item	0	0	50	50	0	0	50	50	SEM	CrNic	L-carnitine	MTO	Int.[y]
45.4 to 106.6 kg BW													
ADG (kg)	0.93	0.93	0.93	0.96	0.95	1.01	0.97	0.99	0.027	0.19	0.70	0.03	0.28
ADFI (kg)	2.49	2.44	2.50	2.35	2.51	2.57	2.59	2.46	0.074	0.20	0.60	0.10	0.17
G/F	0.37	0.38	0.37	0.40	0.38	0.39	0.37	0.40	0.037	0.02	0.41	0.64	0.20
Dressing (%)	74.15	74.49	74.30	74.95	74.64	73.81	74.81	74.63	0.470	0.93	0.12	0.69	0.07
Backfat (cm)													
10th rib	1.65	1.50	1.63	1.83	1.75	1.68	1.60	1.65	0.112	0.86	0.83	0.39	0.30
Average[w]	2.44	2.31	2.44	2.54	2.44	2.49	2.44	2.44	0.083	0.84	0.87	0.99	0.64
LMA (cm^2)	36.77	37.81	37.74	38.45	38.77	39.42	39.23	40.65	0.491	0.44	0.39	0.15	0.70
Lean (%)[v]	53.97	54.96	54.35	53.52	54.07	54.41	54.76	54.98	0.744	0.79	0.50	0.79	0.45
Belly firmness													
Initial (cm)	11.25	12.07	12.83	14.22	18.67	17.02	20.78	13.21	1.593	–	0.81	–	0.04*a*
5 min (cm)	9.53	10.11	11.00	12.40	14.86	13.79	16.51	11.38	1.058	–	0.91	–	0.04*a*

[z]Values are means of two pigs per pen and five replicate pens per dietary treatment.
[y]Hot carcass weight was used as a covariate in the statistical model for carcass characteristics and belly weights and lengths were used as covariates in the statistical model for belly firmness.
[x]Interaction refers to the probability value of the most significant two- or three-way interaction.
[w]Average backfat is the average of the first and last rib and last lumbar backfats.
[v]Lean percentage was derived from National Pork Producers Council (NPPC 1991) equations with 5% fat in the carcass.
*a*Modified tall oil × CrNic interaction ($P = 0.04$); MTO with no CrNic > all other treatment combinations and MTO with CrNic > no MTO with no CrNic ($P < 0.05$).

Bacon Characteristics

Production Traits

Bacon slices from pigs supplemented with MTO were firmer ($P < 0.001$) than slices from pigs fed no MTO (3.91 vs. 2.79, respectively; Table 5). All other bacon production characteristics were similar ($P > 0.10$) among treatments.

Sensory Evaluation

A CrNic × L-carnitine interaction was observed ($P = 0.03$) for the off-flavor attribute (Table 5). Bacon from pigs supplemented with CrNic and L-carnitine had higher ($P < 0.05$) off-flavor scores (less total off-flavor) than bacon from pigs supplemented with CrNic and no L-carnitine (7.73 vs. 7.54, respectively). Off-flavor of bacon from pigs fed no CrNic with L-carnitine (7.59) and CrNic with no L-carnitine (7.54) were intermediate and similar ($P > 0.05$) to those of other interaction treatments. Pigs fed CrNic produced bacon that had more ($P < 0.05$) aftertaste than pigs receiving no CrNic (4.21 vs. 4.10, respectively). Panelists' sensory evaluations of bacon for brittleness, flavor intensity, and saltiness were similar ($P > 0.05$) among treatments.

DISCUSSION

Diets containing MTO improved daily gain and CrNic improved feed efficiency, but no additive effect was detected among MTO, CrNic, and L-carnitine for growth performance traits. Delany et al. (1999) observed an increase in serum insulin with 1% supplemented CLA. The lack of growth response to supplemental L-carnitine agrees with the earlier data of Owen et al. (1994, 2001b) and Smith et al. (1994). These authors concluded that the inability of added fat to elicit a growth response was not altered by supplemented L-carnitine. Previous studies (Owen et al. 1994, 2001b; Smith et al. 1994) had observed reductions in backfat thickness and(or) increased percentage lean of pigs with additions of 50 to 125 ppm of added L-carnitine, contrary to our findings. Since initial carnitine status was not determined in the present study it is unknown if this contributed to the contrasting carcass results.

Pigs fed CrNic had improved G:F, which is similar to results of Lindemann et al. (1995) who found supplementing CrPic increased G:F in pigs. However, work by Smith et al. (1994, 1997) and O'Quinn et al. (1998) has shown CrNic to be ineffective in increasing G:F. Page et al. (1993) demonstrated that 50 and 200 μg kg^{-1} chromium from CrPic increased ADG in growing-finishing pigs but did not affect G:F or measures of carcass leanness. In agreement, carcass lean was not affected; however, the lack of response observed for ADG in the current study may have resulted from all experimental animals being high-lean deposition, lightweight gilts.

For the entire trial, feeding MTO increased ADG. O'Quinn et al. (1999) also observed increases in ADG and G:F during the initial grower phase from feeding MTO, but this response disappeared when measured over the entire growing-finishing period. With CLA, improvements have also been observed in ADG (Thiel et al. 1998) and G:F (Dugan et al. 1997). In a review, Haumann (1996) concluded that the ability of supplemented CLA to improve growth characteristics would still be observed even in the presence

Table 3. Influence of modified tall oil (MTO), chromium nicotinate (CrNic), and (or) L-carnitine on tenth rib longissimus muscle and subcutaneous fat characteristics at 26 h postmortem[z]

	MTO (%)												
	0	0	0	0	0.50	0.50	0.50	0.50					
	CrNic (μg kg^{-1})												
	0	50	0	50	0	50	0	50					
	L-carnitine (mg kg^{-1})									Probability			
Item	0	0	50	50	0	0	50	50	SEM	CrNic	L-carnitine	MTO	Int.[y]
Longissimus													
Visual color[x]	2.70	2.70	2.40	2.00	2.10	2.10	2.30	2.15	0.174	0.49	0.65	0.13	0.10
Firmness[x]	2.35	2.35	2.50	2.10	2.25	2.30	2.50	2.30	0.189	0.60	0.43	0.40	0.31
Marbling[x]	2.15	2.00	2.20	1.90	1.85	1.95	2.25	1.95	0.142	0.16	0.29	0.80	0.21
*L**[w]	58.72	58.78	58.71	60.99	62.25	60.05	58.27	59.52	1.933	0.80	0.68	0.60	0.23
*a**[w]	8.47	8.70	8.54	8.43	8.26	8.77	8.76	8.78	0.613	0.71	0.86	0.81	0.64
*b**[w]	15.70	16.48	16.40	17.03	16.76	16.91	16.11	16.96	0.685	0.22	0.74	0.56	0.35
Drip loss, (%)	4.23	5.31	4.22	5.61	5.85	5.52	5.47	6.10	0.596	0.35	0.27	0.53	0.26
Subcutaneous fat													
L*[w]	83.76	83.89	84.09	83.82	84.33	84.41	85.15	84.19	0.696	0.61	0.65	0.20	0.46
a*[w]	1.52	0.77	1.59	1.33	1.15	1.80	1.13	1.57	0.354	0.94	0.73	0.70	0.07
b*[w]	10.31	9.24	9.32	10.17	9.91	10.17	10.19	9.79	0.655	0.85	0.93	0.58	0.17

[z]Values are means of two pigs per pen and five replicate pens per dietary treatment.
[y]Interaction refers to the probability value of the most significant two- or three-way interaction.
[x]Scale of 1 to 5: 2 = grayish pink, soft and watery, or traces to slight; 3 = reddish pink, slightly firm and moist, or small to modest; and 4 = purplish red, firm and moderately dry, or moderate to slightly abundant for color, firmness, and marbling, respectively.
[w]Means were derived from two sample readings per longissimus muscle. Measures are dark to light (*L**), redness (*a**), and yellowness (*b**).

of additional supplemented fats. Our results were in agreement, because MTO tended to stimulate feed intake even in the presence of supplemental soybean oil.

In the current study, dietary supplements of MTO, CrNic, and L-carnitine did not affect carcass traits. Carcass traits from pigs fed the three supplements singularly have been inconsistent (Boleman et al. 1995; Waylan et al. 2002) but the trend has been for decreased fat and increased lean. The combination of feeding these supplements has not been evaluated. Dietary CLA (Thiel et al. 1998) or carnitine supplementation (Owen et al. 1994; Smith et al. 1994) has been shown to reduce backfat and increase carcass leanness and CrNic (Smith et al. 1994) has also been shown to decrease backfat in pork carcasses. However, these effects were not observed in some other studies (Smith et al. 1997; O'Quinn et al. 1998; Ramsay et al. 2001) or in the present experiment. This may have been the consequence of the genetic leanness of the light, market-weight gilts slaughtered in this study, the composition of the CLA mix in MTO, or the total fat content in the diet may have differed enough to cause variable response among these studies. Furthermore, Stangl et al. (1999) found feeding CLA to pigs increased circulating insulin by 37% but glucose concentrations remained unchanged. A partial explanation for the sporadic responses to chromium supplementation may be the high level of chromium found naturally in corn and soybean meal. This background level ranges up to 6 mg kg^{-1} (P. R. O'Quinn, unpublished data). If even a small portion of this level is biologically available, it could mask the effects of supplemental chromium, especially when added at the current level of 50 μg kg^{-1}.

Thiel et al. (1998) determined that bellies were firmer from finisher pigs fed CLA compared to pigs receiving no supplement. We also observed an improvement in belly firmness in MTO-supplemented pigs. The mechanism for the actions of CLA in pigs is explained by Ramsay et al. (2001). These authors found increased percentages of palmitic and stearic acids in backfat from swine fed CLA, which indicated Δ^9 stearoyl-CoA desaturase was inhibited. However, a MTO and CrNic interaction was observed for belly firmness. In the current study, pigs fed MTO with CrNic had decreased belly firmness compared to bellies from pigs fed MTO with no CrNic. These results agree with Grela et al. (1997) who found the fatty acid composition of backfat in pigs supplemented with chromium had a significant increase in polyunsaturated fatty acid and a decrease in saturated fatty acid level, which would decrease belly firmness. Therefore, we conclude that the improvement in firmness due to MTO was partially reduced by the actions of CrNic.

The addition of MTO appears to partially offset the negative impact of soybean oil on fat firmness. In comparison to results of O'Quinn et al. (1999, 2000), the belly firmness values in the present trial were much lower. However, this is the first study to utilize gilts or supplemental oil in diets with MTO, and the gilts were slaughtered at a relatively light weight. Undoubtedly, the oil and high percentage lean of the gilts contributed to the generally decreased belly firmness compared to that of barrows in other studies. However, the magnitude of the average response in belly firmness from feeding MTO (+ 26.0%) compared to pigs fed diets not containing MTO was greater than previously reported for barrows fed diets without supplemental oil (O'Quinn et al.

Table 4. Influence of modified tall oil (MTO), chromium nicotinate (CrNic), and (or) L-carnitine supplementation on pork moisture, Warner-Bratzler shear force (WBSF), and sensory panel evaluations[z]

	MTO (%)												
	0	0	0	0	0.50	0.50	0.50	0.50					
	CrNic (μg kg^{-1})												
	0	50	0	50	0	50	0	50					
	L-carnitine (mg kg^{-1})									Probability			
Item	0	0	50	50	0	0	50	50	SEM	CrNic	L-carnitine	MTO	Int.[y]
pH at 7 d	5.61	5.63	5.60	5.59	5.57	5.54	5.63	5.63	0.043	0.91	0.42	0.59	0.13
Loin purge loss (%)	1.70	2.02	2.14	2.78	2.41	2.70	1.91	2.04	0.320	0.14	–	–	0.02*a*
Thawing loss (%)	1.39	1.31	1.92	2.03	2.75	1.69	1.34	1.34	0.471	0.45	0.71	0.73	0.07
Cooking loss (%)	28.75	26.73	28.29	28.11	26.49	27.74	27.00	27.17	1.200	0.82	0.80	0.31	0.29
WBSF (kg)	2.77	3.13	3.15	3.12	3.08	2.94	3.01	3.52	0.253	0.33	0.23	0.61	0.16
Sensory evaluation[x]													
Myofibrillar tenderness	6.35	6.07	6.06	6.25	6.04	5.88	5.78	5.75	0.206	0.62	0.40	0.04	0.57
Connective tissue	7.36	7.04	7.22	7.22	7.10	7.15	7.08	6.94	0.112	0.21	0.55	0.09	0.12
Overall tenderness	6.46	6.12	6.15	6.29	6.09	5.98	5.84	5.78	0.205	0.53	0.31	0.03	0.36
Juiciness	5.58	5.22	5.49	5.23	5.21	5.18	5.36	5.45	0.136	0.16	0.38	0.40	0.09
Flavor intensity	5.80	5.57	5.76	5.62	5.66	5.58	5.59	5.66	0.094	0.16	0.96	0.33	0.18
Off-flavor	7.59	7.62	7.70	8.77	8.73	7.60	7.49	7.63	0.591	0.94	0.98	0.89	0.15

[z]Values are means of two pigs per pen and five replicate pens per dietary treatment.
[y]Interaction refers to the probability value of the most significant two- or three-way interaction.
[x]Scores of 1 to 8: myofibrillar tenderness 5 = slightly tender, 6 = moderately tender; connective tissue 6 = traces, 7 = practically none; overall tenderness 5 = slightly tender, 6 = moderately tender; juiciness 5 = slightly juicy; or off-flavor 7 = practically none, 8 = none.
a Modified tall oil × L-carnitine interaction ($P = 0.02$); MTO with no L-carnitine > no MTO with no L-carnitine ($P < 0.05$).

1999, 2000). Recently, Woodworth et al. (1999) demonstrated a belly firming effect from feeding MTO regardless of sex or fat source and level.

Color attributes and drip loss percentage of the LM were not affected by dietary treatment combinations at 26 h postmortem. Smith et al. (1997) observed that CrNic and L-carnitine alone did not influence LM color, but when fed in conjunction, improved it. In the current study, the addition of MTO to the combination of CrNic and L-carnitine was not beneficial to visual color. Additionally, Dugan et al. (1999) and Eggert et al. (1999) observed that CLA did not affect visual color of the LM, whereas Thiel-Cooper et al. (1999) and Larsen et al. (1999) found that a^* values were increased with CLA supplementation.

Dietary treatments can influence fat color (Waylan et al. 2002). In the current study objective color values were not affected by dietary treatment combinations. In contrast, Waylan et al. (2002) found lower L^* and higher a^* values of fat from pigs fed MTO.

Objective measurements of WBSF found tenderness to be similar among treatments. Other authors also found that pork tenderness did not differ for chops from pigs supplemented with CLA (Dugan et al. 1999; Thiel-Cooper et al. 1999) or chromium (Page et al. 1992; Boleman et al. 1995).

The LM sensory panel traits of connective tissue amount, juiciness, flavor intensity, and off-flavor attributes were similar among treatments. Myofibrillar and overall tenderness scores for chops from pigs fed no MTO indicated a more tender chop than the sensory scores from pigs fed MTO. However, this difference was not supported by WBSF values. Thiel-Cooper et al. (1999) found sensory scores to be similar for all characteristics except initial juiciness and Dugan et al. (1999) found no sensory differences for chops from pigs receiving CLA supplementation. Although not statistically different, purge was less from loins of pigs not fed MTO than from pigs fed MTO. Potentially, more moisture was retained in chops from pigs not fed MTO resulting in a more tender product.

The differences in bacon slice firmness in the present study can be attributed to MTO supplementation. Other studies (O'Quinn et al. 1999, 2000) observed firmer bellies from pigs supplemented with MTO than those from control pigs. In addition, Thiel et al. (1998) and Eggert et al. (1999) reported firmer bellies from swine supplemented with CLA. Shackelford et al. (1990) reported consumer panelists' scores for eating quality were influenced not only by the sensory attributes, but also by the visual appearance of the bacon. Even though a slight difference was detected for off-flavor, attributing it specifically to the dietary supplementation was difficult because all values were above 7.5 (8 = no off-flavors). These off-flavors may have resulted from volatile compounds (Mottram 1984) formed from interactions between the added ingredients of salt, nitrite, sugars, phosphates, and flavorings in the bacon.

CONCLUSIONS

Supplementing swine simultaneously with MTO, CrNic, and L-carnitine was not advantageous for growth characteristics. The absence of interactions may be due to several factors, including the duration of feeding the additives, nutrient content of the base diet, level of MTO, CrNic, and L-carnitine required when fed together, or the genetic leanness of

Table 5. Influence of modified tall oil (MTO), chromium nicotinate (CrNic), and (or) L-carnitine supplementation on bacon quality and sensory traits[z]

	MTO (%)												
	0	0	0	0	0.50	0.50	0.50	0.50					
	CrNic (μg kg^{-1})												
	0	50	0	50	0	50	0	50					
	L-carnitine (mg kg^{-1})									Probability			
Item	0	0	50	50	0	0	50	50	SEM	CrNic	L-carnitine	MTO	Int.[y]
Quality evaluations[x]													
Slice firmness[c]	3.15	2.75	2.65	2.60	3.75	3.90	4.10	3.90	0.307	0.57	0.73	0.0001	0.26
Holes	5.60	5.80	5.85	5.30	5.70	5.80	5.70	5.50	0.310	0.61	0.54	0.87	0.24
Thickness	1.02	1.00	1.03	1.17	1.09	1.07	1.04	1.10	0.067	0.41	0.39	0.66	0.22
Sensory analysis[w]													
Brittleness	4.61	4.80	4.81	4.70	4.66	4.85	4.73	4.55	0.160	0.85	0.78	0.77	0.15
Flavor intensity	5.05	4.88	4.80	4.77	4.67	4.82	4.71	4.86	0.093	0.70	0.32	0.11	0.06
Saltiness	4.59	4.45	4.39	4.42	4.42	4.37	4.38	4.52	0.101	0.95	0.68	0.60	0.24
Aftertaste	4.23	4.23	4.10	4.14	4.04	4.15	4.02	4.32	0.079	0.05	0.75	0.46	0.11
Off-flavor	7.74	7.53	7.68	7.69	7.66	7.55	7.49	7.78	0.095	–	–	0.53	0.03*a*

[z]Values are means of two pigs per pen and five replicate pens per dietary treatment.
[y]Interaction refers to the probability value of the most significant two- or three-way interaction.
[x]Scores of 1 to 8: 1 = very soft oily, 8 = very brittle and crumbly; 1 = high number of holes, 8 = no holes; or thickness of cured belly at one-third the length of the bacon slab from the cranial end.
[w]Scores of 1 to 8: brittleness 4 = slightly soft; flavor intensity 4 = slightly bland, 5 = slightly intense; saltiness 4 = slightly unsalty; aftertaste 4 = slight; off-flavor 7 = practically none.
a CrNic × L-carnitine interaction ($P = 0.03$); CrNic with L-carnitine > CrNic with no L-carnitine ($P < 0.05$).

the light, market-weight gilts slaughtered in this study.

In the added fat diets used in these experiments, addition of L-carnitine was not beneficial to growth performance, carcass leanness, or LM color. Dietary additions of MTO, CrNic, and L-carnitine to growing and finishing diets for swine had minimal effects on LM quality characteristics and bacon manufacturing characteristics. However, supplementation of modified tall oil improved bacon slice firmness. Therefore, producers can take advantage of any production or carcass cutability improvement of these feed supplements with only minimal effect on LM or bacon quality.

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