

# Effects of modified tall oil and creatine monohydrate on growth performance, carcass characteristics, and meat quality of growing-finishing pigs<sup>1,2</sup>

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**ABSTRACT:** The effects of feeding modified tall oil (MTO) and creatine monohydrate (CMH) on growing-finishing pig growth performance, carcass characteristics, and meat quality were determined. Eighty crossbred barrows (initially 45.4 kg) were allotted randomly to one of four dietary treatments by weight and ancestry. The experiment was arranged as a 2 × 2 factorial with two levels of MTO (0 or 0.50%), which were fed throughout the growing-finishing period, and two levels of CMH (0 or 25 g/d), which were fed for the final 10 d before slaughter. The corn-soybean meal diets were fed in two phases (45.4 to 78.9 kg and 78.9 to 117.5 kg BW). When CMH was added to the diet in place of corn, average BW was 107.5 kg. Feeding MTO increased ( $P < 0.05$ ) ADG and gain:feed ratio (G/F) during the 45.4- to 78.9-kg growth interval and tended to improve ( $P = 0.10$ ) G/F during the 45.4- to 107.5-kg growth interval. Dietary treatment did not affect ( $P > 0.15$ ) growth per-

formance during the 78.9- to 107.5-kg growth interval. Modified tall oil increased ( $P = 0.02$ ) G/F during the 10-d CMH supplementation period, and CMH numerically ( $P = 0.11$ ) increased ADG and G/F. Supplementation of CMH did not affect ( $P > 0.20$ ) any measured carcass characteristic or measures of meat quality at 24 h or 14 d postmortem. Feeding MTO reduced average backfat ( $P = 0.05$ ) and 10th rib backfat ( $P = 0.01$ ) but did not affect ( $P > 0.10$ ) other measured carcass characteristics or measures of meat quality at 24 h postmortem. Modified tall oil increased ( $P = 0.02$ ) L\* values (lightness) and tended to increase ( $P \leq 0.10$ ) thawing and cooking losses of longissimus muscle chops at 14 d postmortem. These data demonstrate that MTO improves growth performance and reduces backfat in growing-finishing pigs, but supplementation of CMH, under the conditions of this experiment, was not beneficial for growing-finishing pigs.

Key Words: Carcass Composition, Creatine, Meat Quality, Tall Oil

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## Introduction

Creatine is an amino acid derivative occurring predominantly in skeletal muscle (Balsom et al., 1994). Endogenous synthesis of creatine plus dietary contribution average 2 to 4 g/d, with half excreted as creatinine (Juhn and Tarnopolsky, 1998a,b). Creatine functions

in maintaining cellular ATP homeostasis (Harris et al., 1992). Fatigue during maximal exercise of short duration is partially the result of phosphocreatine (PCr) depletion and inability of phosphocreatine hydrolysis to maintain a high ATP:ADP ratio (Greenhaff, 1996). Thus, nonendurance athletes routinely ingest 20 to 25 g/d of creatine for a short-term loading period (Toler, 1997). Creatine loading results in increased water retention (Juhn, 1999). Cellular hydration is an anabolic proliferative signal for protein synthesis (Haussinger et al., 1993). Thus, creatine supplementation could be expected to increase weight gain and percentage lean; however, the effects of creatine monohydrate (CMH) supplementation in swine are largely unknown.

Modified tall oil (MTO) is a rich source of conjugated linoleic acid (CLA) and has been shown to improve growth performance (O'Quinn et al., 1999b) and carcass characteristics (O'Quinn et al., 1999c, 2000a,b) and to play a role in improving meat quality (Waylan et al., 1999a) in finishing swine. Potentially, the combination of MTO and CMH could cause greater improvements

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in growth performance, carcass leanness, and meat quality than either alone. It has been shown that MTO enhances the tissue incorporation of  $\alpha$ -tocopherol (O'Quinn et al., 1999a) and thus improves color stability in pork longissimus muscle (Waylan et al., 1999a). If MTO alters the tissue incorporation of CMH in a similar manner, then improvements in color and water-holding capacity may be observed from their combination.

Therefore, this study was conducted to examine the effects of supplementation of MTO and CMH on growth performance, carcass characteristics, and meat quality in growing-finishing swine.

## Materials and Methods

Pigs used in this experiment were terminal offspring of PIC L326 or 327 boars  $\times$  C22 sows (PIC, Franklin, KY). Experimental procedures were approved by the Kansas State University Institutional Animal Care and Use Committee (Protocol No. 1639).

The 80 crossbred barrows (initial mean pen average of 45.4 kg BW) were blocked on the basis of initial weight and ancestry in a randomized complete block design and allotted randomly to one of four dietary treatments arranged as a 2  $\times$  2 factorial with 10 replicate pens per treatment. Because two of the four dietary treatments were not implemented until 10 d before slaughter, there were 20 pens per dietary treatment until then.

Diets were formulated to meet or exceed nutrient requirements set forth by the NRC (1998) for pigs of this weight with high lean-gain potential and were fed in meal form in two phases (45.4 to 78.9 and 78.9 to 117.5 kg BW; Table 1). Preselected pens of pigs were changed to CMH-supplemented diets at 10 d before slaughter (107.5 kg BW). Modified tall oil was substituted on an equal weight basis for soybean oil, and CMH (CREASURE; pharmaceutical grade, 99% pure creatine monohydrate, SKW Trostberg AG, Germany) was substituted on an equal weight basis (0.75% of the total diet) with ground corn to achieve the additional dietary treatments. The targeted level of creatine intake chosen for this experiment (25 g/d for 10 d) was based on the data of Berg et al. (1999) in swine and on the paper of Williams and Branch (1998) reviewing creatine loading in human athletes. The average of actual creatine intakes was 27.75 g/d in the present study. All diets were analyzed for CP (AOAC, 1995) and creatine and creatinine (Tausky and Kurzmann, 1954; Table 1) using a modified Jaffe method for the creatine analysis. As expected, the basal diets had negligible amounts of both creatine and creatinine.

Pigs were housed in an environmentally controlled finishing barn with two pigs in each 1.33-  $\times$  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 in order to determine ADG, ADFI, and gain/feed (G/F) and also at the beginning and end

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

Item	Grower <sup>a</sup>	Finisher <sup>b</sup>	10 d before slaughter <sup>c</sup>
Ingredient, %			
Corn	69.24	78.58	77.83
Soybean meal (46.5% CP)	27.47	18.39	18.39
Limestone	1.06	0.89	0.89
Monocalcium phosphate	0.85	0.76	0.76
Soybean oil <sup>d</sup>	0.50	0.50	0.50
Salt	0.35	0.35	0.35
Vitamin premix <sup>e</sup>	0.25	0.25	0.25
Trace mineral premix <sup>f</sup>	0.15	0.15	0.15
Antibiotic <sup>g</sup>	0.13	0.13	0.13
Creatine monohydrate <sup>h</sup>	—	—	0.75
Dietary analyses, %			
Creatine <sup>i</sup>	0.04	0.05	0.83
Creatinine <sup>i</sup>	0.02	0.02	0.04
CP <sup>i</sup>	17.71	15.17	15.07

<sup>a</sup>Grower diets were fed from 45.4 to 78.9 kg BW and were formulated to contain 1.00% lysine, 0.65% Ca, and 0.55% P.

<sup>b</sup>Finisher diets were fed from 78.9 to 117.5 kg BW and were formulated to contain 0.75% lysine, 0.55% Ca, and 0.50% P.

<sup>c</sup>Diets were fed for 10 d prior to slaughter (107.5 to 117.5 kg BW) and were formulated to contain 0.75% lysine, 0.55% Ca, and 0.50% P.

<sup>d</sup>Modified tall oil was substituted on an equal weight basis for soybean oil to give the experimental treatments.

<sup>e</sup>Provided per kg of complete diet: vitamin A, 8,818 IU; vitamin D<sub>3</sub>, 1,322 IU; vitamin E, 35.27 IU; menadione (menadione dimethylpyrimidinol bisulphite), 3.52 mg; vitamin B<sub>12</sub>, 0.03 mg; riboflavin, 7.94 mg; pantothenic acid, 26.46 mg; and niacin, 44.10 mg.

<sup>f</sup>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.

<sup>g</sup>Provided 110 mg/kg tylosin.

<sup>h</sup>Creatine monohydrate was substituted on an equal weight basis (0.75% of total diet) for corn during the last 10 d of the finisher period to achieve the additional dietary treatments.

<sup>i</sup>Values represent the average of all diets within each growth period.

of the CMH supplementation period. Serum samples also were obtained from the same pig per pen at the beginning and end of the CMH supplementation period for determination of initial and final creatinine levels (Tausky and Kurzmann, 1954). Feed was not withheld from pigs prior to blood sampling. Only pigs not being slaughtered were bled so that the stress of bleeding would not interfere with or influence measures of meat quality. Serum samples for creatinine analysis were stored frozen ( $-11.5^{\circ}\text{C}$ ) until they were analyzed.

One pig (closest to the average weight of all pigs) per pen was slaughtered at the Kansas State University abattoir after 10 d of receiving or not receiving CMH (average slaughter weight of 117.5 kg). Standard carcass measurements; visual analyses of the longissimus muscle for coloring, marbling, and firmness (NPPC, 1991); drip loss (Kauffman et al., 1986); water-holding capacity (Grau and Hamm, 1953); ultimate pH; and color spectrophotometry ( $L^*$ ,  $a^*$ , and  $b^*$ ; CIE, 1976) were obtained for each pig at 24 h postmortem (drip loss determined at 48 h postmortem). Color spectrophotometry measurements (two surface readings per chop)

were determined with a Hunter Lab MiniScanXE Model 45/OLAV using illuminant C (Hunter Associates Laboratory, Reston, VA). Boneless loins (412B pork loin, boneless, center-cut, eight ribs; NAMP, 1997) were removed from the right sides of all carcasses, vacuum-packaged, and stored for 14 d at 4°C. Purge loss, drip loss, water-holding capacity, pH, visual analysis, and color spectrophotometry were determined again after loins were removed from vacuum bags and allowed 15 min to air-dry. A 2.54-cm-thick chop was also taken from each loin and used for the determination of Warner Bratzler shear force values (AMSA, 1995), using a V-blade attachment for an Instron Model 5401 (Instron Corp., Canton, MA) compression machine. The speed of the V-blade during all measurements was 250 mm/min. Cores (1.27 cm diameter) used for the tenderness evaluations were taken parallel to the muscle fiber orientation. Prior to testing, chops were cooked to an internal core temperature of 70°C in a Blodgett DFG-100-3 Series dual-flow gas convection oven (The G. S. Blodgett Ovens Co., Burlington, VT). Internal temperature was monitored with thermocouples attached to a DORIC Minitrend 205 temperature monitor (Emerson Electric S. A., Doric Div., San Diego, CA). Raw and cooked chop weights were recorded for the determination of percentage thawing and cooking losses.

Data were analyzed as a randomized complete block. The experimental unit for the growth performance data was pen and that for the carcass characteristics and serum creatinine measurements was individual pig (one pig/pen). Performance data for the last 10 d of the finishing period and all carcass data were analyzed as a 2 × 2 factorial arrangement with main effects of MTO (0 or 0.50% of the diet) or CMH (0 or 25 g/d for 10 d preslaughter) using the GLM procedure of SAS (1988). The statistical model included main effects and interactions of the main effects. Hot carcass weight was used as a covariate in the statistical model for quantitative carcass measurements.

## Results

### Growth Performance

Feeding MTO increased ( $P < 0.05$ ) ADG and G/F during the 45.4- to 78.9-kg growth period but had no effect ( $P > 0.15$ ) on growth performance during the 78.9- to 107.5-kg period (Table 2). The improvements in growth performance from feeding MTO during the initial phase resulted in an overall (45.4 to 107.5 kg) tendency ( $P = 0.10$ ) for improved G/F. The 10-d addition of CMH numerically ( $P = 0.11$ ) increased ADG and G/F (Table 3). Modified tall oil increased G/F ( $P = 0.02$ ) and tended to increase ADG ( $P = 0.08$ ) during the CMH supplementation period (107.5 to 117.5 kg BW).

### Carcass Characteristics

Supplementing CMH for 10 d prior to slaughter had no effect ( $P > 0.20$ ) on carcass characteristics or serum

**Table 2.** Growth performance of barrows fed modified tall oil (MTO) from 45.4 to 107.5 kg BW<sup>a</sup>

Item	MTO, %		SEM	Probability
	0	0.50		
45.4 to 78.9 kg BW				
ADG, kg	1.06	1.11	0.017	0.04
ADFI, kg	2.82	2.82	0.041	0.97
Gain/feed	0.37	0.39	0.018	0.03
78.9 to 107.5 kg BW				
ADG, kg	1.08	1.06	0.029	0.66
ADFI, kg	3.43	3.32	0.063	0.20
Gain/feed	0.31	0.32	0.030	0.43
45.4 to 107.5 kg BW				
ADG, kg	1.07	1.08	0.016	0.52
ADFI, kg	3.09	3.03	0.041	0.35
Gain/feed	0.34	0.36	0.018	0.10
Final BW, kg	107.1	108.0	0.820	0.47

<sup>a</sup>Values are means of 20 replicate pens per treatment and two pigs per pen.

creatinine levels (Table 4). Feeding MTO reduced ( $P < 0.05$ ) 10th and last rib backfat, which also resulted in reduced ( $P = 0.05$ ) average backfat. Modified tall oil did not affect ( $P > 0.10$ ) other carcass characteristics or serum creatinine levels.

### Meat Quality

Dietary treatment did not affect ( $P > 0.10$ ) any meat quality traits at 24 h postmortem (Table 5). Supplementation of CMH did not affect ( $P > 0.20$ ) any meat quality traits at 14 d postmortem (Table 6), but feeding MTO increased ( $P = 0.02$ ) L\* values and tended to increase ( $P < 0.10$ ) thawing and cooking losses of chops. Modified tall oil did not affect ( $P > 0.15$ ) other measures of meat quality at 14 d postmortem, including pH, other color determinations, drip loss, water-holding capacity, or shear force.

## Discussion

The initial (45.4- to 78.9-kg BW period) increases in ADG and G/F from feeding MTO (a rich source of CLA) agree with results of O'Quinn et al. (1999c), who also observed an initial improvement in growth performance with MTO that had disappeared by the time pigs reached market weight. Other studies with MTO have either shown no effect (O'Quinn et al., 2000a) or improvements (O'Quinn et al., 1999b) in growth performance over the entire growing-finishing period. Dugan et al. (1997) and Thiel et al. (1998) have also reported improvements in growth performance from dietary supplementation with CLA.

Creatine monohydrate supplementation did not affect growth performance, although numerical increases were observed in both ADG and G/F. Berg et al. (1999) reported that pigs supplemented with CMH at 25 g/d for 10 d preslaughter had a lower ham semimembranosus muscle CP:moisture ratio, suggesting greater myofiber

**Table 3.** Growth performance of barrows fed modified tall oil (MTO), creatine monohydrate (CMH), or both from 107.5 to 117.5 kg BW<sup>a</sup>

Item	0 MTO		0.50% MTO		SEM	Probability values ( <i>P</i> =)		
	CMH, g/d		CMH, g/d			MTO × CMH	MTO	CMH
	0	25	0	25				
ADG, kg	1.02	1.09	1.10	1.28	0.075	0.46	0.08	0.11
ADFI, kg	3.71	3.61	3.54	3.79	0.101	0.09	0.95	0.48
Gain/feed	0.26	0.29	0.30	0.34	0.099	0.80	0.02	0.11
Final BW, kg	113.9	117.0	118.0	117.3	1.826	0.38	0.19	0.46

<sup>a</sup>Values are means of 10 replicate pens per treatment and two pigs per pen.

hydration. This observation in the muscle could be extended to the live animal; however, tissues were not analyzed for CP or moisture in the present experiment. Also, the lack of differences in growth performance or water-holding capacity and shear-force values determined postmortem may indicate that any increased retention of water in the live animal was not maintained.

The reductions in backfat from feeding MTO agree with earlier data of O'Quinn et al. (1999c, 2000a,b) and with data from feeding CLA to pigs (Dugan et al., 1997; Thiel et al., 1998). Other than in the data of O'Quinn et al. (2000a), MTO does not seem to increase longissimus muscle area; thus, any increases in calculated percentage lean (NPPC, 1991) are due primarily to decreases in backfat. This is somewhat opposite to results of Dugan et al. (1997), who concluded that CLA repartitions nutrients from fat deposition to lean deposition. Modified tall oil seems to reduce backfat without repartitioning nutrients to actual lean deposition and largely without improving growth performance. Improved G/F values would be expected with reduced backfat, because lean pigs are more efficient at converting feed to lean

gain. However, G/F was improved only marginally by feeding MTO from 45.4 to 107.5 kg; thus, it was not likely the major cause of the reduced backfat.

Creatine supplementation in human athletes has been reported to increase weight gain and fat/bone-free mass without affecting body fat (Earnest et al., 1995; Kreider et al., 1998). At least three possible explanations exist for the lack of increased muscle mass from CMH supplementation in the present experiment: 1) the supplementation period was too short; 2) barrows in this weight range are predominantly depositing adipose tissue instead of lean tissue; and 3) ingestion of large doses of creatine by humans usually is accompanied by physical exertion, which leads to muscular hypertrophy. Creatine does not trigger muscle differentiation but serves as a modulator of muscle protein biosynthesis (Walker, 1979); thus, muscle hypertrophy apparently must be initiated before CMH supplementation can increase lean mass. In a review of creatine supplementation and athletic performance, Juhn and Tarnopolsky (1998a) concluded that creatine supplementation increased strength, possibly through increased

**Table 4.** Carcass characteristics of barrows fed modified tall oil (MTO), creatine monohydrate (CMH), or both<sup>a,b</sup>

Item	0 MTO		0.50% MTO		SEM	Probability values ( <i>P</i> =)		
	CMH, g/d		CMH, g/d			MTO × CMH	MTO	CMH
	0	25	0	25				
Shrink loss, %	0.65	0.88	1.02	0.83	0.198	0.30	0.39	0.87
Backfat, cm								
First rib	4.17	4.04	3.78	3.94	0.156	0.39	0.11	0.83
Tenth rib	2.39	2.51	2.03	2.16	0.131	0.96	0.01	0.30
Last rib	2.31	2.49	2.06	2.21	0.112	0.87	0.02	0.24
Last lumbar	2.21	2.31	1.98	2.16	0.129	0.73	0.19	0.28
Average <sup>c</sup>	2.90	2.95	2.62	2.77	0.117	0.65	0.05	0.50
Longissimus muscle area, cm <sup>2</sup>	40.06	42.00	42.00	41.16	0.574	0.33	0.78	0.76
Lean % <sup>d</sup>	51.14	51.24	53.19	52.22	0.913	0.56	0.18	0.49
Dressing %	73.88	73.72	73.58	73.74	0.342	0.66	0.21	0.36
Carcass length, cm	82.17	83.38	83.19	82.61	0.600	0.14	0.84	0.94
Serum creatinine, mg/L								
Initial	1.37	1.40	1.50	1.40	0.058	0.29	0.30	0.52
Final	1.55	1.58	1.66	1.58	0.069	0.45	0.50	0.70

<sup>a</sup>Values represent 10 replicate pens per treatment and one pig per pen.

<sup>b</sup>Hot carcass weight was used as a covariate in the statistical analysis of quantitative carcass measurements.

<sup>c</sup>Average backfat is the average of the first and last rib and last lumbar fat depths.

<sup>d</sup>Lean percentage was derived from NPPC (1991) equations.

**Table 5.** Quality measures of longissimus muscle at 24 h postmortem in barrows fed modified tall oil (MTO), creatine monohydrate (CMH), or both<sup>a</sup>

Item	0 MTO		0.50% MTO		SEM	Probability values ( <i>P</i> =)		
	CMH, g/d		CMH, g/d			MTO × CMH	MTO	CMH
	0	25	0	25				
pH	5.41	5.39	5.39	5.40	0.033	0.59	0.70	0.83
Visual color <sup>b</sup>	2.60	2.40	2.45	2.40	0.173	0.67	0.70	0.51
Marbling <sup>b</sup>	2.60	2.30	2.35	2.40	0.159	0.27	0.79	0.58
Firmness <sup>b</sup>	2.95	2.80	2.60	2.80	0.208	0.40	0.64	0.64
L* <sup>c</sup>	56.58	57.19	57.80	56.80	0.873	0.36	0.64	0.82
a* <sup>c</sup>	9.97	9.35	9.98	9.26	0.603	0.94	0.95	0.27
b* <sup>c</sup>	19.28	18.16	18.74	17.48	1.002	0.95	0.55	0.24
Hue angle <sup>c</sup>	62.61	62.92	62.08	62.29	0.523	0.93	0.27	0.62
Saturation index <sup>c</sup>	21.71	20.43	21.24	20.49	0.998	0.80	0.84	0.32
a*/b* <sup>c</sup>	0.52	0.51	0.53	0.53	0.011	0.90	0.28	0.57
%R630/%R580 <sup>c</sup>	2.87	2.72	2.78	2.69	0.115	0.78	0.58	0.30
%R610/%R580 <sup>c</sup>	2.47	2.33	2.39	2.32	0.098	0.75	0.66	0.31
Drip loss, %	5.01	4.20	5.48	5.74	0.813	0.51	0.13	0.98
Water-holding capacity, % <sup>d</sup>	3.36	3.49	3.92	3.60	0.224	0.32	0.15	0.67

<sup>a</sup>Values represent 10 replicate pens per treatment and one pig per pen.

<sup>b</sup>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.

<sup>c</sup>Means were derived from two sample readings per loin. Measures of dark to light (L\*), redness (a\*), yellowness (b\*), red to orange (hue angle), vividness or intensity (saturation index), or reflectance values (%R630/%R580 and %R610/%R580).

<sup>d</sup>Determined by dividing the area of the meat by the area of the fluid after compression with a Carver press.

**Table 6.** Quality measures of longissimus muscle at 14 d postmortem in barrows fed modified tall oil (MTO), creatine monohydrate (CMH), or both<sup>a</sup>

Item	0 MTO		0.50% MTO		SEM	Probability values ( <i>P</i> =)		
	CMH, g/d		CMH, g/d			MTO × CMH	MTO	CMH
	0	25	0	25				
pH	5.43	5.43	5.42	5.42	0.032	0.97	0.65	0.75
Visual color <sup>b</sup>	2.40	2.45	2.45	2.40	0.112	0.64	0.64	0.63
Marbling <sup>b</sup>	2.50	2.40	2.20	2.35	0.173	0.48	0.19	0.81
Firmness <sup>b</sup>	2.90	2.90	2.95	2.90	0.105	0.81	0.99	0.66
L* <sup>c</sup>	55.01	54.99	56.66	56.75	0.720	0.94	0.02	0.96
a* <sup>c</sup>	19.41	21.12	20.87	20.79	0.728	0.23	0.44	0.27
b* <sup>c</sup>	6.90	7.65	7.65	7.72	0.333	0.31	0.23	0.23
Hue angle <sup>c</sup>	21.19	19.93	20.13	20.35	0.671	0.28	0.64	0.45
Saturation index <sup>c</sup>	21.13	22.46	22.22	22.17	0.576	0.24	0.49	0.28
a*/b* <sup>c</sup>	2.67	2.77	2.73	2.70	0.053	0.24	0.96	0.60
%R630/%R580 <sup>c</sup>	2.65	2.79	2.70	2.67	0.075	0.25	0.64	0.48
%R610/%R580 <sup>c</sup>	2.28	2.38	2.33	2.89	0.058	0.22	0.74	0.59
Drip loss, %	1.59	1.65	1.19	1.49	0.384	0.77	0.48	0.66
Water-holding capacity, % <sup>d</sup>	3.77	3.57	3.98	3.65	0.275	0.81	0.59	0.34
Loin purge loss, %	2.93	2.60	3.12	3.50	0.415	0.37	0.16	0.88
Chop thawing loss, %	7.05	6.88	7.62	7.53	0.363	0.91	0.10	0.73
Chop cooking loss, %	26.53	25.81	29.17	29.53	1.772	0.76	0.09	0.92
Chop shear force, kg	2.55	2.60	2.71	2.87	0.151	0.73	0.17	0.51

<sup>a</sup>Values represent 10 replicate pens per treatment and one pig per pen.

<sup>b</sup>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.

<sup>c</sup>Means were derived from two sample readings per loin. Measures of dark to light (L\*), redness (a\*), yellowness (b\*), red to orange (hue angle), vividness or intensity (saturation index), or reflectance values (%R630/%R580 and %R610/%R580).

<sup>d</sup>Determined by dividing the area of the meat by the area of the fluid after compression with a Carver press.

myofibrillar protein synthesis. Greenhaff (1996) noted that 20 to 30% of individuals ingesting creatine do not show a response. This was attributed to type of athlete (endurance vs nonendurance) or inability to incorporate creatine into the muscle. Endurance athletes typically do not respond favorably to creatine supplementation, because the increased mass and water retention are not conducive to the athletic events in which they participate. However, Vandenberghe et al. (1997) demonstrated that long-term creatine supplementation and initiation of resistance training for previously sedentary females enhanced muscle strength more than resistance training alone. Greenhaff (1996) determined a minimal level of creatine accumulation in muscle necessary to observe benefits from additional supplementation. This level can be achieved by a short-term loading period such as 20 to 25 g/d for 5 to 10 d followed by a long-term intake of a low dose such as 2 to 3 g/d (Hultman et al., 1996). In the present study, muscle samples were not assayed for creatine levels. More work is needed in this area to determine whether creatine supplementation to swine can be beneficial without physical exertion.

Additionally, CMH supplementation did not increase serum creatinine levels in this experiment. Plasma creatinine (the sole metabolite of creatine) levels have been identified as useful indicators of total body mass of striated muscle (Schutte et al., 1981) when plasma volume is also known. Schutte et al. (1981) also indicated that overnight fasting was required for a proper assessment of creatinine levels in the blood. Kreider et al. (1998) and Hultman et al. (1996) reported that creatinine levels increased after creatine supplementation. Harris et al. (1992) have reported increases in serum creatinine following creatine supplementation; however, other studies (as cited by Kreider et al., 1998) have not shown increases in serum creatinine after supplementation of creatine. Because calculated percentage lean did not increase in the present study, the lack of an effect on creatinine levels by CMH supplementation is not surprising.

Dietary treatment did not affect measures of color or water-holding capacity at 24 h postmortem. Modified tall oil increased  $L^*$  values and tended to increase thawing and cooking losses of longissimus chops at 14 d postmortem. In a previous experiment (O'Quinn et al., 2000a) MTO decreased drip loss percentage and  $b^*$  values in longissimus muscle at 24 h postmortem. Additionally, MTO fed in conjunction with vitamin E did not affect color measurements of the longissimus muscle at 24 h postmortem (O'Quinn et al., 1999c) but maintained a longer display color stability (Waylan et al., 1999a). Assessments of pork quality measures such as pH, taste panel evaluations, shear-force determinations, oxidative status, and display color stability have either shown minimal effects (Waylan et al., 1999b) or improvements (Waylan et al., 1999a) from dietary MTO supplementation. The absolute increase in  $L^*$  values (lightness) at 14 d postmortem from feeding MTO com-

pared to pigs not fed MTO was 1.71 units, which is only marginally noticeable to a typical consumer. The slightly increased thawing and cooking losses from MTO supplementation are not readily explainable. Berg et al. (1999) concluded that CMH supplementation decreased drip loss and  $L^*$  values, but these results were not observed in the present experiment.

Berg et al. (1999) also noted that CMH supplementation might allow for more intramuscular fat deposition. This is an interesting concept, because most carcass modifiers that increase lean mass do so at the expense of adipose tissue. Although CLA has been shown to increase intramuscular marbling (Dugan et al., 1999), as has MTO (O'Quinn et al., 2000b), supplementation with CMH or MTO did not increase marbling in this study.

Neither MTO nor CMH supplementation affected water-holding capacity measures. The proposed mechanisms behind water-holding capacity in fresh meat are quite complex and often contradictory but are affected by postmortem pH decline, processing factors, and nutrition (den Hertog-Meischke et al., 1997). Indirect measures such as  $L^*$  values have not yielded reliable assessments of the true water-holding capacity in porcine muscle (van Laack et al., 1994). The rate of pH decline was not measured in the current study, but the ultimate pH (24 h postmortem) was similar to that reported by Waylan et al. (1999a) using the same type of pigs. Additionally, the cooking and thawing losses and shear-force values observed in the current study were similar to those reported by Waylan et al. (1999a). The increases routinely observed in water retention from creatine supplementation coupled with potential myofiber swelling could alter tenderness of the longissimus muscle. However, instrumentally determined tenderness was not affected by dietary treatment.

## Implications

These results indicate that modified tall oil may improve measures of growth performance (namely, feed efficiency) and reduces backfat in growing-finishing swine. The increased lean mass that human athletes routinely gain from creatine supplementation does not seem to be applicable in a modern swine nutrition program. A short-term, large dose (25 g/d for 10 d) of creatine monohydrate does not influence growth performance, carcass characteristics, or meat quality. Different approaches to creatine supplementation using varying levels of creatine or lengths of supplementation (i.e., a long-term basal inclusion in addition to a loading period) may be necessary to fully identify its potential benefits for growing-finishing pigs.

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