Effects of modified tall oil and vitamin E on growth performance, carcass characteristics, and meat quality of growing-finishing pigs[1,2]

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ABSTRACT: Crossbred barrows (n = 72) were used to evaluate effects of diet supplementation with modified tall oil (MTO; 0.0 or 0.50%) and vitamin E (0, 22, or 110 IU/kg) on growth performance, carcass traits, and longissimus muscle (LM) quality traits of finishing pigs. Pigs were blocked by ancestry and initial BW and allotted randomly to treatments in a 2 × 3 factorial. Corn-soybean meal-based diets were fed in two phases: 45.5 to 81.6 (1.00% lysine) and 81.6 to 114.6 (0.75% lysine) kg BW with no added fat. From 45.5 to 81.6 kg, pigs fed MTO had greater ADG ($P = 0.03$) regardless of added vitamin E; otherwise, treatment did not affect growth performance. Carcasses from pigs fed MTO had reduced ($P < 0.05$) average backfat (2.76 vs 2.92 cm) and firmer bellies compared to those fed no MTO. Boneless loins were cut into 2.54-cm chops at 7 d postmortem and evaluated for display color, thiobarbituric acid-reactive substance (TBARS), Warner-Bratzler shear force (WBSF), and sensory panel ratings. Visual color was similar ($P > 0.05$) among treatments at 0 and 1 d of display. At 4 and 6 d of display chops from pigs fed MTO with 110 IU vitamin E/kg had less deterioration ($P < 0.05$) than chops from pigs fed MTO with 0 IU vitamin E/kg and 0.0% MTO with 22 or 110 IU vitamin E/kg. The CIE L*, a*, b* and spectral values also suggested a delay in color deterioration for chops from pigs fed MTO with 110 IU vitamin E/kg. At 6 and 8 d of display, chops from pigs fed 110 IU vitamin E/kg had lower ($P < 0.05$) L* values than those from pigs fed 0 or 22 IU vitamin E/kg, and higher ($P < 0.05$) a* values than those from pigs fed 0 IU vitamin E/kg feed. A higher ($P < 0.05$) %R630/%R580 (indicator of more oxymyoglobin) was observed for chops from pigs fed MTO with 110 IU vitamin E/kg than those from pigs fed 0.0% MTO with 22 or 110 IU vitamin E/kg and MTO with 0 IU vitamin E/kg. Chops from pigs fed MTO with 110 IU vitamin E/kg had lower ($P < 0.05$) TBARS values than those from pigs fed MTO with 0 IU vitamin E/kg. No differences ($P > 0.05$) were detected among treatments for WBSF or sensory evaluations. The addition of MTO in swine diets improved belly firmness and reduced backfat, and feeding MTO with high levels of vitamin E extended display life without affecting palatability of LM chops.

Key Words: Vitamin E, Growth, Animal Tissues, Meat Quality, Pigs, Conjugated Linoleic Acid

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Introduction

Tall oil is a nonaqueous layer of rosin acids and fatty acids produced during the kraft paper process. Modified tall oil (**MTO**) has a high content of conjugated linoleic acid (**CLA**, 67.4%) and is from further processing the fatty acid portion of tall oil. O'Quinn et al. (2000b) determined growth performance of pigs was not affected by dietary supplementation of MTO or a commercial source of CLA (CLA-60); however, when compared to that of pigs fed the control diet, adipose tissue was more saturated. Additionally, Unruh et al. (2000) concluded feeding 0.5% MTO decreased average backfat 4%, increased longissimus area 3%, and increased belly firmness 15% in pork carcasses.

Nicolosi et al. (1997) observed that hamsters fed increasing concentrations of CLA had increased plasma vitamin E. They suggested CLA may be tocopherol-sparing and act directly or indirectly as an antioxidant. Additionally, O'Quinn et al. (1999a) reported internal fat of rats fed MTO had higher α-tocopherol levels than control rats.

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Vitamin E is a natural, lipid-soluble antioxidant that protects cell membranes from oxidative damage. Mitsumoto et al. (1993) found vitamin E supplementation improved meat color by α-tocopherol's ability to prevent oxidation of myoglobin and(or) oxymyoglobin to metmyoglobin. In addition, Monahan et al. (1994a) and Asghar et al. (1991a) concluded incorporation of α-tocopherol via the diet is effective in extending shelf life. However, Dirinck et al. (1996) and Stika (1998) observed display color to be unaffected by vitamin E supplementation.

Vitamin E and MTO may improve pork quality by increased saturation of lipids, reduced number of free radicals, and enhanced vitamin E uptake providing stronger antioxidant abilities. For these reasons, this study was undertaken to evaluate diet supplementation with MTO and vitamin E on pork quality characteristics.

Materials and Methods

Animals and Diets

Crossbred barrows (n = 72; L326 or 327 boars × C22 sows; PIC, Franklin, KY) were blocked by BW (initially 46 kg) and ancestry then randomly allotted to one of six dietary treatments in a 2 × 3 factorial arrangement. Pigs were fed two levels of MTO (0.0% and 0.50% MTO of diet) and three levels of added vitamin E (0, 22, or 110 IU/kg of feed). There were two pigs in each pen and six pens (observations) per treatment. The fatty acid profile of the MTO used in this experiment was determined using methods described by O'Quinn et al. (2000b). It contained 1.69% palmitic acid, 1.59% palmitoleic acid, 26.76% oleic acid, 3.32% α-linoleic acid, and 66.63% CLA. The CLA fraction was also separated into its *cis* (*c*) and *trans* (*t*) isomeric components. The CLA fraction was comprised of 32.15% *c*9, *t*11; 19.69% *t*9, *t*11; 16.10% *c*10, *c*12; 19.38% *t*10, *c*12; and 12.68% unidentified CLA isomers. Dietary inclusion of 0.50% MTO was chosen because O'Quinn et al. (2000b) found it was the optimal level that reduced backfat, increased longissimus muscle (**LM**) area, improved color characteristics, and decreased drip loss.

Formulated levels of added dietary vitamin E were 0, 22, and 110 IU/kg (analyzed vitamin E was 16.25, 40.85, and 98.5 IU/kg, respectively). The basal grower diet was fed in meal form from 45.5 kg to 81.6 kg BW and was formulated to contain 1.00% total lysine (Table 1). The basal finisher diet was fed in meal form from 81.6 kg to 114.6 kg BW and was formulated to contain 0.75% total lysine. Modified tall oil (0.0% or 0.5%) or vitamin E premix (0, 22, or 110 IU/kg) replaced cornstarch in the basal diets to provide additional dietary treatments.

Pigs were housed in an environmentally controlled finishing barn in 1.33- × 1.33-m totally slatted pens. They 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, ADFI, and gain:feed ratio. As the pigs neared the target final weight of 114 kg, they were weighed every 7 d.

Slaughter and Carcass Fabrication

When the mean weight of pigs in a block reached 114.6 kg, the entire block was transported to the Kansas State University abattoir. Pigs were loaded onto a stock trailer at 1800 and transported approximately 10 min to the abattoir. Pigs were deprived of feed overnight and then at 0600 slaughtered humanely using standard industry procedures approved by the Kansas State University Animal Care and Use Committee. At approximately 45 min postmortem, carcasses were moved into a cooler and chilled at –2°C. Carcasses were 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. Carcasses were then ribbed between the 10th and 11th ribs, and 10th rib fat depth was measured over the LM ¾ 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, marbling, and firmness (NPPC, 1991). Objective color (L*, a*, and b*; CIE, 1976) of the LM and subcutaneous fat were also obtained. Color spectrophotometry measurements (two surface readings per LM or adipose tissue 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, Reston, VA). 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 for 5 min and measuring the distance from end to end.

Boneless Loin Fabrication

From the wholesale loin, a 23-cm boneless loin was removed from the 10th rib and posterior. The boneless loin was weighed, vacuum-packaged, and aged for an additional 6 d at 1°C. At 7 d postmortem each loin was faced at the 10th rib surface and cut into 2.54-cm chops. Cutting anterior to posterior, chops were assigned as follows: 1) display color; 2) 0-d thiobarbituric acid-reactive substance (**TBARS**); 3) 4-d TBARS; 4) sensory panel; 5) sensory panel; and 6) Warner-Bratzler shear force (**WBSF**). Display color and 4-d TBARS chops were immediately placed individually on a soaker pad (U.S. Packaging, Maxton, NC) on a white 2S styrofoam tray (Tenneco, Canandaigua, NY) and overwrapped with oxygen-permeable polyvinyl chloride film (21,700 cc O_2/m^2). Sensory panel, 0-d TBARS, and WBSF chops were

Table 1. Composition of basal diets (%, as-fed basis)

Ingredient	Grower[a]	Finisher[b]
Corn	68.71	78.03
Soybean meal (46.5% CP)	27.50	18.43
Limestone	1.05	0.88
Cornstarch[c]	1.00	1.00
Monocalcium phosphate	0.86	0.78
Salt	0.35	0.35
Vitamin premix[d]	0.25	0.25
Trace mineral premix[e]	0.15	0.15
Antibiotic[f]	0.13	0.13
Analyzed CP[g]	17.90	15.21

[a]Diets were fed from 45.5 to 81.6 kg BW and were formulated to contain 1.00% lysine, 0.65% Ca, and 0.55% total P. Analyzed vitamin E was 14.25, 42.65, and 94.15 IU/kg for 0, 22, and 110 IU/kg, respectively.
[b]Diets were fed from 81.6 to 114.6 kg BW and were formulated to contain 0.75% lysine, 0.55% Ca, and 0.50% total P. Analyzed vitamin E was 16.25, 40.85, and 98.5 IU/kg for 0, 22, and 110 IU/kg, respectively.
[c]Modified tall oil and vitamin E additions replaced an equal weight of cornstarch to provide the additional dietary treatments.
[d]Provided per kg of complete diet: vitamin A, 8,818 IU; vitamin D_3, 1,322 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.
[e]Provided per kg of complete diet: Zn, 165.3 mg; Fe, 165.3 mg; Mn, 39.7 mg; Cu, 16.5 mg; I, 0.3 mg; and Se, 0.3 mg.
[f]Provided 110 mg tylosin/kg (Elanco Animal Health, Indianapolis, IN).
[g]Values represent the average of all diets within each growth period.

crust-frozen for 30 min at –40°C, individually vacuum-packaged, and stored at –40°C until analysis.

Display Color

Chops were displayed in open-top display cases (2 ± 2°C; Model DMF8, Tyler Refrigeration, Niles, MI) with continuous lighting (intensity 1,614 lx; Philips Deluxe Warm White 40-W fluorescent lights; Philips Lighting, Salina, KS). Visual display color was evaluated by nine panelists trained according to meat color evaluation guidelines (AMSA, 1991). The 5-point color scale used (Clark, 1998) consisted of 1 = bright grayish-pink or reddish-pink, 2 = grayish-pink or reddish-pink, 3 = slightly dark pink/red to brown, 4 = moderately dark pink/red to brown, and 5 = dark pink/red to brown. Chops were scored to the nearest 0.50. A score of 3.5 indicated a point when the product had sufficient visual color deterioration to potentially be unsellable (Clark, 1998). Spectral data and CIE L*, a*, and b* (CIE, 1976) values were measured using a Spectrocolorimeter (LabScan2000 0/45, 2.54-cm diameter aperture, Illuminant C, 10° observer, Hunter Associates Laboratory). Three surface readings per sample were taken and averaged. The ratio of reflectance, %R630 nm/%R580 nm was determined. Chops were evaluated visually and instrumentally, after 30 min of bloom time, on the 1st d of display (0 d) and then at 1, 2, 4, 6, and 8 d of display. Chops were randomly rotated daily within the display case to decrease potential environmental effects.

Lipid Oxidation

The extent of lipid oxidation was measured as TBARS at 0 and 4 d of display. The 4-d TBARS chops were displayed under the conditions previously described for the visual color display. After 4 d of display, chops were frozen and stored at –40°C along with the previously processed 0-d TBARS chops. The TBARS values were determined by the extraction method of Witte et al. (1970). Duplicate samples from each chop were averaged and expressed as milligrams of malonaldehyde per kilogram of DM.

Palability Traits

The chops for WBSF were thawed at 2°C for 24 h in the vacuum bags with the seals 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., 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). Chops were cooled at room temperature (21°C) for 1 h, reweighed, and subsequently chilled for 24 h at 2°C. Six random (free of connective tissue) 1.27-cm-diameter cores were then 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). A 50-kg compression load cell was used at a crosshead speed of 250 mm/min. The six values for each sample were averaged for statistical analysis. Percentages of thawing and cooking losses were calculated as 100 × (initial chop weight – thawed chop weight)/initial chop weight and 100 × (thawed chop weight – cooked chop weight)/thawed chop weight, respectively.

The chops for sensory panel evaluation were thawed at 2°C for 24 h in their vacuum bags with the seals

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. Seven members of a trained (AMSA, 1995) descriptive attribute sensory analysis panel each evaluated two samples from each chop. Samples were evaluated 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 evaluated on 8-point scales to 0.50 intervals. 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.

Statistical Analysis

Data were analyzed as a randomized complete block design with dietary treatments arranged as a 2 × 3 factorial with main effects of MTO (0.0% or 0.50% of the diet) and added vitamin E (0, 22, or 110 IU/kg). Initial weight and ancestry were used to establish blocks. Statistical analyses for growth, carcass, and LM characteristics were performed with the GLM procedure of SAS (SAS Inst. Inc., Cary, NC) 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. For comparisons pertaining to measurements over time, a split-plot analysis using the Mixed procedure of SAS was done to account for repeated measurements that included the fixed effects of treatment and display day as the repeated measure. Satterthwaite adjustment was used for the degrees of freedom in the Mixed procedure. All main effect and interaction means were separated ($P < 0.05$) using the Least Significant Difference procedure when the respective F-tests were significant ($P < 0.05$).

Results

Growth Performance

No interactions ($P > 0.45$) of MTO and vitamin E were observed during any of the growth performance intervals or over the entire trial (Table 2). Vitamin E did not affect ADG, ADFI, or gain:feed. Pigs fed MTO had greater ADG ($P = 0.03$) than pigs fed 0.0% MTO (1.22 vs 1.17 kg/d, respectively) during the initial 45.5- to 81.6-kg interval. Additionally, during the first growth interval pigs fed MTO tended to have greater gain:feed ($P = 0.09$) than pigs fed 0.0% MTO. However, ADG, ADFI, and gain:feed were similar during the 81.6- to 114.6-kg interval. Overall, neither MTO nor added vitamin E altered ($P > 0.60$) growth performance.

Carcass Characteristics

No interactions ($P > 0.29$) between MTO and vitamin E were observed for carcass characteristics (Table 3), and vitamin E did not affect ($P > 0.16$) any measured carcass characteristic. Feeding MTO decreased overall backfat ($P = 0.004$) compared to 0.0% MTO (2.76 vs 2.92 cm, respectively). Modified tall oil did not affect ($P > 0.20$) dressing percentage, LM area, or percentage lean. Bellies were firmer ($P = 0.04$) from pigs fed MTO than from those receiving 0.0% MTO (34.28 vs 30.08 cm, respectively).

Longissimus Muscle and Adipose Tissue Color

Interactions of MTO and vitamin E occurred ($P < 0.05$) for firmness and drip loss of the LM (Table 4). In pigs fed 0.0% MTO, added vitamin E decreased firmness, but firmness was similar among vitamin E treatments fed with MTO. In pigs not fed MTO, increasing added vitamin E increased then decreased drip loss, whereas increasing added vitamin E appeared to decrease drip loss in pigs fed MTO. Additionally, an interaction ($P = 0.03$) of MTO and vitamin E occurred for b* values (yellowness) of the LM. Added vitamin E increased b* values in pigs not fed MTO but did not influence b* values in pigs fed MTO. Neither MTO nor vitamin E alone affected ($P > 0.20$) any other LM color traits.

No interactions ($P > 0.05$) of vitamin E and MTO were observed for subcutaneous fat color characteristics. Subcutaneous fat from pigs fed MTO compared to that from pigs not fed MTO had increased ($P = 0.0001$) a* values (2.02 vs 1.33) and decreased ($P = 0.0002$) L* values (whiteness; 84.86 vs 86.23).

Display Color

An MTO × vitamin E × display time interaction ($P = 0.02$) was observed for visual color (Figure 1). Scores for each treatment were consistently higher ($P < 0.001$) at each progressing evaluation period. At 0 and 1 d, no differences ($P > 0.05$) were observed among treatments. At 2, 4, 6, and 8 d, chops from pigs fed MTO with 110 IU vitamin E/kg had lower (less deterioration; $P < 0.05$) visual color scores than those from pigs fed MTO with 0 IU vitamin E/kg. At 4 d, chops from pigs fed MTO with 110 IU vitamin E/kg had lower visual color scores ($P < 0.05$) than those from pigs fed 0.0% MTO with 22 or 110 IU vitamin E/kg. In addition, chops from pigs fed MTO with 22 or 110 IU vitamin E/kg had lower color scores ($P < 0.05$) than those from pigs fed MTO with 0 IU vitamin E/kg. At 6 d, chops from pigs fed MTO with 110 IU vitamin E/kg had lower color scores

Table 2. Growth performance of pigs fed modified tall oil (MTO) and increasing levels of vitamin E[a]

	MTO, %:	0			0.50				Probability (P =)		
Item	Vitamin E, IU/kg:	0	22	110	0	22	110	SEM	MTO × E	MTO	E
45.5 to 81.6 kg BW											
ADG, kg		1.16	1.17	1.18	1.19	1.24	1.22	0.026	0.68	0.03	0.51
ADFI, kg		2.91	2.93	2.88	2.91	3.03	2.91	0.050	0.68	0.34	0.20
Gain:feed		0.40	0.40	0.41	0.41	0.41	0.42	0.022	0.98	0.09	0.39
E intake, mg/d[b]		41	131	284	42	123	261	—	—	—	—
81.6 to 114.6 kg BW											
ADG, kg		1.11	1.16	1.09	1.08	1.16	1.08	0.038	0.90	0.65	0.16
ADFI, kg		3.59	3.72	3.66	3.57	3.76	3.55	0.110	0.77	0.73	0.29
Gain:feed		0.31	0.31	0.30	0.30	0.31	0.30	0.029	0.45	0.73	0.48
E intake, mg/d[b]		59	147	370	57	159	341	—	—	—	—
45.5 to 114.6 kg BW											
ADG, kg		1.14	1.16	1.13	1.14	1.20	1.16	0.024	0.75	0.33	0.18
ADFI, kg		3.25	3.32	3.27	3.24	3.39	3.23	0.072	0.75	0.93	0.21
Gain:feed		0.35	0.35	0.35	0.35	0.35	0.36	0.019	0.60	0.22	0.92
E intake, mg/d[b]		50	139	326	50	141	278.31	—	—	—	—

[a]Values are means of six replicate pens per dietary treatment and two pigs per pen.
[b]Calculated by multiplying ADFI and analyzed dietary vitamin E content.

($P < 0.05$) than those from pigs fed 0.0% MTO with 0, 22, or 110 IU vitamin E/kg. Also, chops from pigs fed MTO with 22 IU vitamin E/kg, 0.0% MTO with 0 or 110 IU vitamin E/kg had lower color scores ($P < 0.05$) than those from pigs fed MTO with 0 IU vitamin E/kg. At 8 d, chops from pigs fed MTO with 110 IU vitamin E/kg had lower color scores ($P < 0.05$) than those from pigs fed all other treatments. Additionally, chops from pigs fed MTO with 22 IU vitamin E/kg and 0.0% MTO with 110 IU vitamin E/kg had lower color scores ($P < 0.05$) than those from pigs fed MTO with 0 IU vitamin E/kg.

The LM display L* values were similar ($P = 0.54$) for chops from pigs fed MTO (56.92) and 0.0% MTO (57.33). An interaction of vitamin E × day of display was detected ($P < 0.001$) for CIE L* values (Figure 2). At 0, 1, 2, and 4 d of display, no differences ($P > 0.05$) for L* were observed among concentrations of vitamin E. At 6 and 8 d of display, chops from pigs fed 110 IU vitamin E/kg had lower (darker; $P < 0.05$) L* values than those from pigs fed 0 or 22 IU vitamin E/kg. For pigs fed 0 IU vitamin E/kg, LM L* values were progressively higher ($P < 0.05$) at each display period after 2 d of display. For pigs fed 22 IU vitamin E/kg, LM L* values were higher ($P < 0.05$) at 4, 6, and 8 d than at 0 d. For pigs fed 110 IU vitamin E/kg, LM L* values were higher ($P < 0.05$) at 1, 2, 4, and 6 d than at 0 d.

The LM display a* values (an indication of redness) were similar ($P = 0.76$) for chops from pigs fed diets with (7.05) or without MTO (6.96). However, chops from pigs fed 110 IU vitamin E/kg (7.47) had higher ($P = 0.02$) a* values than those from pigs receiving 0 IU vitamin E/kg (6.52).

The a* values for chops were higher ($P < 0.05$) at 0 and 1 d than at all other days of display (Table 6). The a* values for chops decreased ($P < 0.05$) at each day of display after 2 d. For b* values (an indication of yellowness), no differences ($P > 0.05$) were detected among dietary treatments. Display b* values were the highest ($P < 0.05$) for chops at 0 d compared to all other days of display. The b* values for chops were higher ($P < 0.05$) at 1 d than at 2, 4, 6, or 8 d and higher ($P <$

Table 3. Carcass characteristics of pigs fed modified tall oil (MTO) and increasing concentrations of vitamin E[a,b]

	MTO, %:	0			0.50				Probability (P =)		
Item	Vitamin E, IU/kg:	0	22	110	0	22	110	SEM	MTO × E	MTO	E
Dressing percentage		74.99	75.13	75.23	75.24	75.44	74.98	0.349	0.72	0.93	0.97
10th rib fat depth, cm		2.67	2.57	2.49	2.34	2.49	2.44	0.125	0.52	0.11	0.89
Average backfat, cm[c]		3.02	2.95	2.79	2.72	2.84	2.72	0.071	0.29	0.004	0.16
Loin muscle area, cm^2		34.90	35.68	34.97	35.42	35.81	36.06	0.400	0.65	0.78	0.90
Percentage lean[d]		48.41	48.96	49.14	49.97	49.23	49.71	0.725	0.65	0.20	0.90
Belly firmness, cm		31.12	30.53	28.60	33.40	35.51	33.93	2.339	0.73	0.04	0.69

[a]Values are means of six replicate pens per dietary treatment and two pigs per pen.
[b]Hot carcass weight was used as a covariate in the statistical model for carcass characteristics. Belly weight and initial length were used as covariates in the statistical model for belly firmness.
[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.

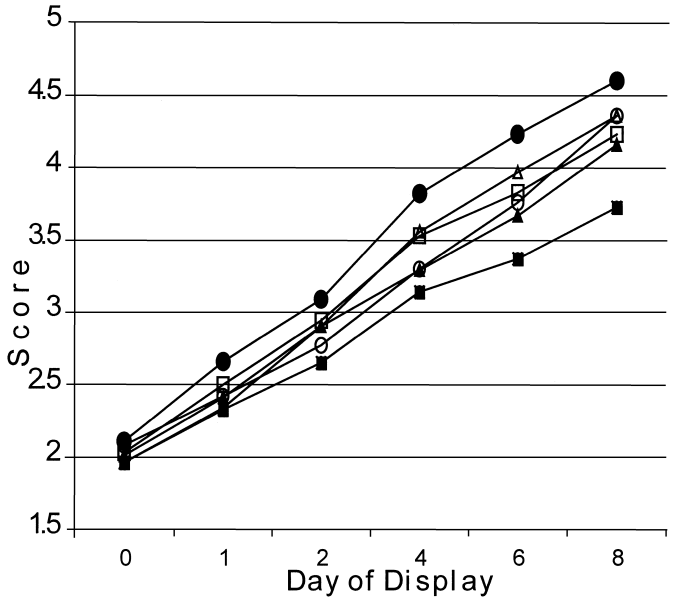

Figure 1. Influence of modified tall oil (MTO), vitamin E supplementation, and day of display on visual color scores of pork loin chops (0% MTO + 0 IU vitamin E/kg (○); 0% MTO + 22 IU vitamin E/kg (△); 0% MTO + 110 IU vitamin E/kg (□); 0.5% MTO + 0 IU vitamin E/kg vitamin E(●); 0.5% MTO + 22 IU vitamin E/kg (▲); 0.5% MTO + 110 IU vitamin E/kg (■)) (SEM = 0.13).

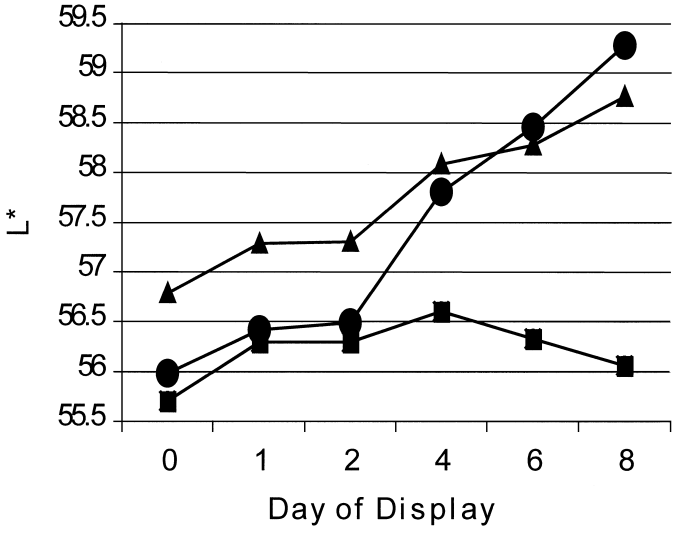

Figure 2. Influence of vitamin E supplementation and day of display on L* values of pork loin chops (0 IU vitamin E/kg (●); 22 IU vitamin E/kg (▲); 110 IU vitamin E/kg (■)) (SEM = 0.60).

0.05) at 2 d than at 4, 6, and 8 d. However, b* values for chops were higher ($P < 0.05$) at 8 d than at 4 and 6 d.

An MTO × vitamin E interaction ($P = 0.008$) was detected for display ratio of reflectance (%R630/%R580; Table 5). A higher ($P < 0.05$) ratio of reflectance (indicator of more oxymyoglobin) was observed for chops from pigs fed MTO with 110 IU vitamin E/kg than for those from pigs fed 0.0% MTO with 22 or 110 IU vitamin E/kg and pigs fed MTO with 0 IU vitamin E/kg. Also, chops from pigs fed MTO with 22 IU vitamin E/kg and 0.0% MTO with 0 IU vitamin E/kg had higher ($P < 0.05$) ratio values than those from pigs fed MTO with 0 IU vitamin E/kg. Ratio of reflectance (%R630/%R580) values for chops decreased ($P < 0.05$) at each evaluation period (Table 6).

Table 4. Tenth rib longissimus muscle and subcutaneous fat characteristics at 26 h postmortem of pigs fed modified tall oil (MTO) and increasing concentrations of vitamin E[a]

	MTO, %:	0			0.5				Probability (P =)		
Item	Vitamin E, IU/kg:	0	22	110	0	22	110	SEM	MTO × E	MTO	E
Longissimus muscle											
Visual color[b]		2.54	2.25	2.08	2.29	2.29	2.46	0.150	0.13	0.59	0.65
Firmness[b]		2.79[f]	2.17[d]	2.21[d]	2.48[def]	2.38[de]	2.63[ef]	0.138	0.04	0.33	0.09
Marbling[b]		2.38	2.08	2.08	2.17	2.13	2.50	0.129	0.07	0.43	0.34
L*[c]		58.34	60.00	58.25	58.87	59.54	57.73	0.983	0.83	0.85	0.20
a*[c]		9.47	10.21	10.87	10.55	9.98	10.28	0.450	0.16	0.81	0.41
b*[c]		16.99[d]	18.97[e]	19.09[e]	18.69[e]	18.15[de]	17.98[de]	0.536	0.03	0.86	0.33
%R630/%R580[c]		2.60	2.66	2.81	2.71	2.65	2.71	0.072	0.40	0.96	0.26
Drip loss, %		3.05[d]	5.12[ef]	3.93[d]	4.71[e]	4.37[de]	3.46[d]	0.467	0.02	0.97	0.26
Subcutaneous fat											
L*[c]		86.43	86.73	85.54	84.36	84.94	85.28	0.398	0.06	0.0002	0.46
a*[c]		1.30	1.07	1.62	2.26	1.87	1.92	0.173	0.16	0.0001	0.13
b*[c]		10.11	10.07	10.12	10.37	10.39	10.10	0.182	0.62	0.22	0.74

[a]Values are means of six replicate pens per dietary treatment and two pigs per pen.
[b]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.
[c]Means were derived from two sample readings per longissimus muscle. Measures are lightness (L*), redness (a*), yellowness (b*), or indicator of the amount of oxymyoglobin present (ratio of reflectance %R630/%R580).
[d,e,f]Means in the same row with a different superscript letter differ ($P < 0.05$).

Table 5. Influence of modified tall oil (MTO) and vitamin E supplementation on display instrumental color and oxidation measurements of pork loin chops

MTO, %:	0			0.5				Probability (P =)		
Item Vitamin E, IU/kg:	0	22	110	0	22	110	SEM	MTO × E	MTO	E
Instrumental color[a]										
L*	56.50	58.57	56.93	58.32	56.93	55.52	0.80	0.07	0.54	0.15
a*	6.86	6.98	7.05	6.19	7.05	7.90	0.32	0.08	0.76	0.02
b*	20.22	20.65	20.36	20.18	20.45	20.33	0.21	0.87	0.54	0.16
%R630/%R580	2.11^{de}	2.00^{cd}	2.07^{cd}	1.92^{c}	2.13^{de}	2.25^{e}	0.06	0.008	0.43	0.08
TBARS[b]	0.54^{cd}	0.78^{cd}	0.67^{cd}	0.94^{d}	0.56^{cd}	0.39^{c}	0.16	0.05	0.79	0.34

[a]Measure of lightness (L*), redness (a*), yellowness (b*), or indicator of the amount of oxymyoglobin present (ratio of reflectance %R630/%R580).
[b]Thiobarbituric acid-reactive substance, mg malonaldehyde/kg DM.
[c,d,e]Means in the same row with a different superscript letter differ ($P < 0.05$).

Lipid Oxidation

An interaction of MTO × vitamin E was detected ($P = 0.05$) for TBARS (Table 5). The chops from pigs fed MTO with 110 IU vitamin E/kg were numerically the lowest and had lower ($P < 0.05$) TBARS values than chops from pigs fed MTO with 0 IU vitamin E/kg. The TBARS values were lower ($P < 0.05$) from chops not displayed (0 d) than those displayed for 4 d (Table 6).

Palability Traits

Thawing loss and cooking loss were determined from chops used for WBSF evaluations. No differences ($P > 0.05$) were detected for thawing loss, cooking loss, and WBSF values among treatments (Table 7).

Sensory traits of myofibrillar tenderness, connective tissue quantity, overall tenderness, juiciness, flavor intensity, and off-flavor scores were similar ($P > 0.05$) among treatments (Table 7). Feeding MTO or vitamin E had no influence on sensory panel traits.

Discussion

Supplementing swine diets with vitamin E did not improve any measures of growth performance (ADG, ADFI, or gain:feed), which is consistent with prior results (Anderson et al., 1995; Cannon et al., 1996; Lepine et al., 1990). This raises the possibility that even though the vitamin E contributed by corn and soybean meal is assumed to be of low bioavailability (Lynch, 1996), it may still meet the nutritional demands of the pig for normal growth and development. Another possibility is that the quantity of vitamin E fed to these pigs before the initiation of this experiment was high enough to sustain normal growth and development. These pigs were fed about 44 IU of added vitamin E/kg from weaning (21 ± 3 d of age) to 23 kg BW and then 35 IU/kg until the initiation of the experiment. Asghar et al. (1991b) concluded that beneficial effects of supranutritional levels of vitamin E on growth performance in pigs were observed only at an early age.

Feeding MTO elicited improvements in ADG and gain:feed but only during the initial growing phase. Ostrowska et al. (1999) found supplementing pigs with CLA high in concentrations of *c*9, *t*11 and *c*10, *t*12 isomers improved gain:feed during the first growth phase. O'Quinn et al. (1999b) noted improvements in ADG and ADFI throughout the growing-finishing period with added MTO. Similar to the present study, O'Quinn et al. (2000a) observed improvements in ADG and gain:feed during the initial growing phase, but only the response in gain:feed was maintained throughout the growing-

Table 6. Influence of day of display on instrumental color and oxidation measurements of pork loin chops

	Day						
Item	0	1	2	4	6	8	SEM
Instrumental color[a]							
a*[e]	8.66^{g}	8.37^{g}	7.63^{f}	7.45^{e}	5.77^{d}	4.15^{c}	0.22
b*[e]	21.50^{g}	21.12^{f}	20.60^{e}	19.30^{c}	19.61^{c}	20.06^{d}	0.20
%R630/%R580[d]	2.79^{c}	2.47^{d}	2.23^{e}	1.84^{f}	1.66^{g}	1.48^{h}	0.04
TBARS[b]	0.19^{c}	—	—	1.10^{d}	—	—	0.11

[a]Measure of redness (a*), yellowness (b*), or indicator of the amount of oxymyoglobin present (ratio of reflectance %R630/%R580).
[b]Thiobarbituric acid-reactive substance, mg malonaldehyde/kg DM.
[c,d,e,f,g,h]Means in the same row with the same superscript do not differ ($P > 0.05$).

Table 7. Influence of modified tall oil (MTO) and vitamin E supplementation on cookery, Warner-Bratzler shear, and sensory panel evaluations of pork loin chops

MTO, %:	0			0.5				Probability (P =)		
Item Vitamin E, IU/kg:	0	22	110	0	22	110	SEM	MTO × E	MTO	E
Thawing loss, %	2.57	2.72	2.92	2.69	2.61	2.74	0.19	0.72	0.73	0.55
Cooking loss, %	25.23	27.22	27.63	26.79	25.67	27.10	0.92	0.25	0.82	0.34
Shear force, kg	2.56	2.84	3.10	3.02	2.92	2.79	0.17	0.09	0.58	0.64
Sensory evaluation										
Myofibrillar tenderness[a]	6.43	6.16	5.86	6.14	6.02	6.26	0.16	0.10	0.94	0.33
Connective tissue[b]	7.59	7.55	7.47	7.65	7.57	7.60	0.07	0.67	0.23	0.46
Overall tenderness[c]	6.55	6.32	6.01	6.30	6.25	6.44	0.16	0.11	0.78	0.43
Juiciness[d]	5.33	5.21	5.25	5.35	5.15	5.32	0.12	0.87	0.95	0.43
Flavor intensity[e]	5.67	5.72	5.74	5.69	5.67	5.69	0.06	0.83	0.60	0.84
Off-flavor[f]	7.79	7.83	7.82	7.82	7.85	7.91	0.07	0.88	0.47	0.70

[a]1 = extremely tough, 8 = extremely tender.
[b]1 = abundant, 8 = none.
[c]1 = extremely tough, 8 = extremely tender.
[d]1 = extremely dry, 8 = extremely juicy.
[e]1 = extremely bland, 8 = extremely intense.
[f]1 = extremely intense, 8 = none.

finishing period. Feeding CLA to swine also increased ADG (Thiel et al., 1998) and gain:feed (Dugan et al., 1997). However, studies with MTO did not show improvement in growth performance (O'Quinn et al., 2000b,c).

Our results are in agreement with Asghar et al. (1991b) and Cannon et al. (1996), who reported vitamin E supplementation did not affect carcass yield measurements. The reductions in backfat from MTO supplementation agree with the results of Dugan et al. (1997), Thiel et al. (1998), and O'Quinn et al. (2000b), all of whom noted a decrease in backfat in swine fed CLA. In mice, Park et al. (1999) noted that feeding CLA enriched for *c*9, *t*11 and *t*10, *c*12 reduced body fat. Modified tall oil increased belly firmness by about 13% in the present study. Woodworth et al. (1999) and O'Quinn et al. (1999b, 2000b) also have shown that MTO increased belly firmness. Furthermore, feeding CLA to growing-finishing pigs increased belly firmness (Thiel et al., 1998). Eggert et al. (1999) concluded that the increase in belly firmness from feeding CLA to swine was due to an increased saturation of the fatty acids present in the adipose tissue from the belly region. This relationship has been confirmed in our laboratory for MTO (O'Quinn et al., 2000b). Taken together, these results suggest a saturating effect of MTO or CLA on adipose tissue is the primary component of increased belly firmness in growing-finishing swine.

Based on the findings of O'Quinn et al. (1999a, 2000b), it seems plausible that MTO increases the saturation of the fat and incorporates vitamin E into the cell membranes. This would explain the potential improvements in drip loss and b* values found in the current study when vitamin E was increased in diets containing MTO.

Subcutaneous fat color was affected by feeding MTO. These data would indicate that feeding MTO results in slightly darker, redder fat. Even though there were differences in the instrumental values, these differences would be hard to detect by subjective visual evaluation.

As expected, visual panel color scores revealed a decline (increased score) in fresh pork color over the 8 d of display. At 6 d, the MTO with 110 IU vitamin E/kg combination was the only treatment that sustained a mean score of less than 3.5, which indicates acceptable display color that should not be discounted in a typical retail case (Clark, 1998).

Overall, feeding pigs MTO with 110 IU vitamin E/kg delayed display color deterioration of the LM. The extended display color exhibited in chops from swine fed a combination of MTO and vitamin E can be explained partially by results from previous studies. Asghar et al. (1991a) concluded that simply feeding high levels of α-tocopheryl acetate in swine diets did not ensure an improvement in pork color stability; the α-tocopherol must be incorporated into the cellular membranes. Research by Nicolosi et al. (1997) suggested that CLA increased the uptake of vitamin E in plasma. Therefore, combining vitamin E and CLA (both with known antioxidant abilities; Ip et al., 1991) may result in elevated cellular membrane α-tocopherol levels that decrease the rate of free radical formation. Hence, lipid oxidation is retarded, increasing muscle stability. However, the mechanism for the increased uptake of α-tocopherol in the presence of CLA remains unknown. In contrast, feeding MTO with no added vitamin E appears to have a deleterious effect on display life. One possible explanation is that increasing the concentration of fat in the diet increased the pig's requirement for vitamin E. Therefore, the vitamin E provided by the basal diet may not be enough to protect the cell membranes from oxidation.

Previous studies have reported that vitamin E was a potent antioxidant that prevented discoloration and extended display life of pork (Monahan et al., 1990,

1994a; Asghar et al., 1991a). Overall, a darker color (lower L* value) was maintained over the display period for chops from pigs fed 110 IU vitamin E/kg in the present study. This may have been associated with the visual color stability observed in LM chops from pigs fed MTO with 110 IU vitamin E/kg. In contrast to our results, Monahan et al. (1994a), Cannon et al. (1996), and Dirinck et al. (1996) found that vitamin E supplementation to swine did not influence LM display L* values. However, Asghar et al. (1991a) and Monahan et al. (1994a) agree with our results; they also detected higher a* values for both fresh and previously frozen pork LM chops from pigs fed 200 mg α-tocopheryl acetate/kg of feed than from LM chops from pigs fed the basal diet (10 mg/kg of feed) after 2, 4, 6, and 8 d of refrigerated storage. Cannon et al. (1996) also found that Hunter a* values decreased over display time. Our results for b* values also agree with those of Monahan et al. (1994b) and Cannon et al. (1996), who reported little difference between LM chops from control pigs or vitamin E-supplemented pigs. The highest numerical ratio of reflectance indicated that feeding pigs MTO with 110 IU vitamin E/kg may result in a LM with a higher ratio of oxymyoglobin to metmyoglobin. A higher oxymyoglobin concentration would be associated with a more desirable bright reddish-pink color (less deterioration). Previous studies have reported that vitamin E was a potent antioxidant that prevented discoloration and extended display life of pork (Monahan et al. 1990, 1994a; Asghar et al., 1991a).

Feeding MTO with 110 IU vitamin E/kg improved lipid stability, which agrees with several other researchers who have provided evidence that supplementation of swine diets with elevated levels of α-tocopheryl acetate results in lower TBARS values (less lipid oxidation) in pork tissue in comparison to corresponding tissues from control pigs (Monahan et al., 1994b; Cannon et al., 1996; Dirinck et al., 1996). However, in the present study the rate of oxidation was not affected by feeding 110 IU vitamin E/kg without MTO. Additionally, feeding MTO without vitamin E did not decrease muscle oxidation. These findings are supported by a model system (van den Berg et al., 1995) that found phospholipid membranes to have oxidative stress in the presence of CLA. Therefore, we conclude that MTO must be fed with high levels of vitamin E to incorporate vitamin E into the lipid component and elicit an antioxidant effect.

The increased display life and reduced lipid oxidation found in longissimus chops from pigs fed MTO with 110 IU vitamin E/kg may be the result of vitamin E being incorporated into the lipid components of the cell membrane. This theory is similar to findings of O'Quinn et al. (1999a) that MTO-supplemented rats had greater α-tocopherol concentrations in abdominal and retroperitoneal fat than rats receiving no MTO. However, without added vitamin E, the basal diet does not provide sufficient vitamin E to prevent discoloration and oxidation, explaining the detrimental effects of MTO on display life. As Morrissey et al. (1994) found, the effectiveness of vitamin E is not only reliant on the concentration fed but on other dietary components such as the fatty acid content. This may partially explain the lack of response to the treatment of MTO with no vitamin E. Alpha-tocopherol may protect the metmyoglobin-reducing systems in meat from free radical attack and hence sustain their activity for longer periods, allowing for the formation of oxymyoglobin instead of metmyoglobin (Faustman and Cassens, 1989). Monahan et al. (1994b) suggested that oxidation of myoglobin precedes lipid oxidation, supporting the contention that metmyoglobin may catalyze the oxidation of muscle lipids. Therefore, if longissimus color deterioration is delayed, lipid oxidation also may be reduced. Feeding high levels of vitamin E has a beneficial effect on pork muscle by preserving the integrity of the muscle cell membranes and preventing the oxidation of membranous phospholipids during refrigerated storage (Monahan et al., 1994b). Another explanation of the antioxidant capabilities of α-tocopherol under refrigerated display storage is that vitamin E is an efficient quencher of singlet oxygen, which normally is generated by fluorescent lighting and causes the formation of metmyoglobin (Foote, 1985). Therefore, the reduced form (oxymyoglobin) of heme iron can be maintained longer in meat from vitamin E-supplemented animals.

Our results support results of Dugan et al. (1999) and Thiel-Cooper et al. (1999), who concluded that dietary CLA supplementation had no impact on shear force values of pork LM. Additionally, Stika (1998) reported that dietary level of vitamin E did not influence WBSF values. Cannon et al. (1996) also found that supplementation of vitamin E did not affect cooking loss. However, Asghar et al. (1991a) and Monahan et al. (1994b) found that feeding high levels of vitamin E (200 IU/kg) reduced thawing loss. Asghar et al. (1991a) hypothesized that higher levels of vitamin E protected the fluidity of the cell membranes from freeze injury.

In our study, diet supplementation with MTO and vitamin E did not affect sensory panel evaluation of pork. Dugan et al. (1999) also found that CLA supplementation to swine did not affect sensory traits. In agreement, Thiel-Cooper et al. (1999) reported that CLA supplementation did not affect most sensory traits of pork LM. However, they found higher scores for juiciness in LM chops from control pigs than in those from pigs supplemented with CLA. Cannon et al. (1996) also reported that vitamin E supplementation did not influence taste panel scores for tenderness, juiciness, pork flavor intensity, or off-flavor. Additionally, Arnold et al. (1993) reported that juiciness scores in beef samples were not affected by vitamin E dietary treatment. These data suggest that use of MTO in swine diets may improve growth performance during the grower phase, increase belly firmness, and reduce backfat. Feeding increasing concentrations of vitamin E with MTO improves display color stability.

Implications

Modified tall oil has been shown to decrease backfat and increase belly firmness. Additions of high levels of vitamin E to swine diets did not improve growth performance, carcass characteristics, or fresh pork color at 26 h postmortem. Feeding modified tall oil in combination with high levels of vitamin E to pigs during both the growing and finishing phases improved display color stability and delayed lipid oxidation of the longissimus muscle without affecting tenderness or sensory evaluations. Therefore, feeding modified tall oil (0.50%) with vitamin E (110 IU/kg) potentially can increase the shelf-life stability of pork and reduce monetary losses from deteriorated product.

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