# Interactive effects of dietary ractopamine HCl and L-carnitine on finishing pigs: II. Carcass characteristics and meat quality[1,2]

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**ABSTRACT:** Three experiments using 1,356 pigs (C22 × 336 PIC) were conducted to determine the interactive effects of dietary L-carnitine and ractopamine hydrochloride (RAC) on carcass characteristics and meat quality of finishing pigs. Experiments were arranged as factorials with main effects of L-carnitine and RAC; L-carnitine levels were 0, 25, or 50 mg/kg in Exp. 1 and 2 and 0 or 50 mg/kg in Exp. 3, and RAC levels of 0, 5, or 10 mg/kg in Exp. 1 and 0 or 10 mg/kg in Exp. 2 and 3. Dietary L-carnitine was fed from 38 kg to slaughter (109 and 118 kg in Exp. 1 and 3, respectively) or for 4 wk before slaughter (109 kg in Exp. 2). Ractopamine HCl was fed for 4 wk in all experiments. Exp. 1 and 2 were conducted at university research facilities (2 pigs per pen), and Exp. 3 was conducted in a commercial research barn (23 pigs per pen). In Exp. 1, an L-carnitine × RAC interaction ($P < 0.02$) was observed for LM visual color, L*, and a*/b*. In pigs fed RAC, increasing L-carnitine decreased L* and increased visual color scores and a*/b* compared with pigs not fed RAC. Ultimate pH tended to increase (linear, $P < 0.07$) with increasing L-carnitine. Drip loss decreased (linear, $P < 0.04$) in pigs fed increasing L-carnitine. In Exp. 2, firmness scores decreased in pigs fed increasing L-carnitine when not fed RAC, but firmness scores increased and drip losses decreased with increasing L-carnitine when RAC was added to the diet (L-carnitine × RAC interaction, $P < 0.04$). Percentage lean was greater ($P < 0.01$) for pigs fed RAC in Exp. 2. In Exp. 3, fat thickness decreased and lean percentage increased in pigs fed L-carnitine or RAC, but the responses were not additive (L-carnitine × RAC interaction, $P < 0.03$). Furthermore, pigs fed L-carnitine tended ($P < 0.06$) to have decreased LM drip loss percentage whereas pigs fed RAC had decreased ($P < 0.05$) 10th rib and average backfat and decreased drip loss than pigs fed diets without RAC. These results suggest that dietary RAC increased carcass leanness and supplemental L-carnitine reduced LM drip loss when fed in combination with RAC.

**Key words:** carcass quality, carnitine, pigs, ractopamine HCl

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## INTRODUCTION

Ractopamine hydrochloride (**RAC**) is a β-agonist that increases protein accretion (Anderson et al., 1987) and decreases protein degradation (Bergen et al., 1989). Cromwell (1991) reported that pigs fed RAC require additional ME for maintenance and had increased protein synthesis; however, this was offset by the reduced energy required because of decreased fat deposition. Because of the low feed intake commonly observed in commercial environments (De La Llata et al., 2001), pigs fed RAC may be in an energy-dependent phase of growth and, therefore, not capable of maximizing protein deposition.

Heo et al. (2000a) demonstrated that L-carnitine is essential for intermediary energy metabolism. A major function of L-carnitine is to transport long-chain fatty acid groups across the mitochondrial membrane into

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the mitochondrial matrix for energy production (ATP) via β-oxidation and oxidative phosphorylation. Adding L-carnitine to the diet could increase the amount of energy available for protein deposition and increase the response to RAC. Added L-carnitine has also been shown to influence the enzymes involved in lactic acid production. Siliprandi et al. (1990) and Vecchiet et al. (1990) observed that added L-carnitine improved aerobic processes (via increased pyruvate dehydrogenase activity) and thus decreased lactate production in exercising humans. Owen et al. (2001) demonstrated that supplementing L-carnitine increased pyruvate carboxylase and decreased lactate dehydrogenase flux in pigs, and a reduction in postmortem lactic acid production would increase pH, thereby leading to possible improvements in meat quality. Thus, the objectives of these experiments were to evaluate interactive effects among L-carnitine, RAC, and dietary energy density on carcass criteria of growing-finishing pigs and differences in LM quality indicators, such as color, marbling, and firmness.

## MATERIALS AND METHODS

All animal procedures were reviewed and approved by the Kansas State University Institutional Animal Care and Use Committee.

### *General*

The pigs used in these experiments were part of a larger project (James et al., 2013) conducted to evaluate the interactive effects of dietary L-carnitine and RAC (Elanco Animal Health, Greenfield, IN) on growth performance of growing-finishing pigs. All pigs used in these experiments were progeny of C22 females × 336 boars (PIC, USA, Hendersonville, TN). In Exp 1 and 2, pigs were housed in an environmentally controlled building with 1.2 $m^2$ pens at the Kansas State University Swine Teaching Research Center (Manhattan, KS). Each slatted-floor pen had a 1-hole self-feeder and a nipple waterer to allow ad libitum access to feed and water.

Exp. 3 was conducted at a commercial research facility in southwestern Minnesota. Pigs were housed in a curtain-sided barn with completely slatted floors. The barn was 12.5 m × 76.2 m with forty-eight 3.05 m × 5.49 m pens. Each pen contained a 4-hole dry self-feeder and a cup waterer to allow ad libitum access to feed and water. Ractopamine HCl was fed for 4 wk before the end of each experiment whereas dietary L-carnitine was fed from approximately 38 kg BW until the end of the study (109 and 118 kg in Exp. 1 and 3, respectively) or 4 wk before the end of the study (109 kg) in Exp. 2. All dietary nutrients were formulated to meet or exceed recommended requirement estimates (NRC, 1998). All diets during the RAC feeding period contained at least 1.00% total Lys to account for the increase in protein deposition observed in pigs fed RAC (Webster et al., 2007).

### *Experiment 1*

Gilts ($n$ = 126) were blocked by BW (33.4 kg) and ancestry in a randomized complete block design. Pens of pigs (2 pigs per pen) were assigned randomly to 1 of 9 experimental treatments arranged in a 3 × 3 factorial (7 replicate pens per treatment). Pigs were fed a corn-soybean meal-based diet (Table 1) formulated with 0, 25, or 50 mg/kg of added L-carnitine from 33.4 kg until slaughter (approximately 109 kg). The basal diet was formulated to contain 1.10% total Lys (18.2% CP) from 33.4 to 74.4 kg and 1.00% total Lys (16.9% CP) from 74.4 kg until the end of the experiment. Dietary RAC (0, 5, or 10 mg/kg) was fed for the last 4 wk of the experiment.

A pig weighing closest to 109 kg was selected from each pen and slaughtered at the Kansas State University Meats Laboratory according to industry-accepted procedures. Hot carcass weight was recorded before carcasses were chilled for 24 h at 0°C. The pH of the LM was measured at 45 min and 24 h postmortem with an Accument Portable pH Probe (Model AP61; Fischer Scientific, Pittsburgh, PA). After the 24-h chilling period, LM temperature, chilled carcass weight, carcass length and backfat depth opposite the first rib, last rib and last lumbar vertebra were measured before right sides were ribbed between the 10th and 11th ribs to measure 10th rib fat thickness and LM area. In addition, the exposed LM was visually appraised for color (1 = pale pinkish gray to white to 6 = dark purplish red; NPPC, 2000), marbling [1 = 1% intramuscular (**i.m.**) fat to10 = 10% i.m. fat; NPPC, 2000), and firmness (1 = soft to 3 = very firm; NPPC, 2000). Instrumental color [lightness (L*), redness (a*), and yellowness (b*) values] was measured with a Minolta colorimeter (CR-310 Konica Minolta, Ramsay, NJ) with a 25-mm aperture and illuminant $D_{65}$ (the mean of 2 readings was used for statistical analysis). Redness (a*) and yellowness (b*) were used to calculate hue angle ($\tan^{-1}$[b*/a*]), saturation index ($\sqrt{a^{*2}+ b^{*2}}$), and the a*/b* ratio. Lastly the 24-h LM drip loss percentage was measured using the filter-paper method of Kauffman et al. (1986).

### *Experiment 2*

Gilts ($n$ = 120) were blocked by initial BW (87.2 kg) and ancestry in a randomized complete block design. Pens of pigs (2 pigs per pen) were assigned to 1 of 6 experimental treatments arranged in a 2 × 3 factorial (10 replicate pens per treatment). Pigs were fed a corn-soybean meal-based diet (1.00% total Lys, 16.9% CP; Table 1) formulated with 0, 25, or 50 mg/kg of added L-carnitine and 0 or 10 mg/kg RAC for the 4-wk experiment.

As in Exp. 1, a single pig weighing closest to 109 kg was selected from each pen and slaughtered at the Kansas State University Meats Laboratory. Blood was collected at exsanguination for quantifying whole blood pH, glucose, and lactate concentrations. Temperature and pH of the LM was measured immediately after exsanguination (designated as 5 min postmortem) and at 15 min, 45 min, 1.5 h, 3 h, 6 h, and 24 h. In addition, carcass cutability data, subjective LM quality scores, instrumental color, and drip loss were measured as described previously.

A 10-g LM tissue sample was obtained at the level of the 11th rib to measure transmission value. The sample was thoroughly mixed with 20 mL of distilled water and stored at 3°C for 24 h before centrifuging at 500 × *g* at 4°C for 20 min. The supernatant was subsequently filtered through #1 Whatman filter paper. The filtrate (1 mL) was mixed with 5 mL of citric acid-phosphate buffer, stored for 30 min at 24°C, and the percentage turbidity was measured at 600 nm (high transmission values indicate less soluble protein and low-quality muscle).

### *Experiment 3*

Barrows ($n$ = 1104) were blocked by initial BW (44.0 kg) in a randomized complete block design. Pens of pigs (23 pigs per pen) were assigned to 1 of 8 experimental treatments arranged in a 2 × 2 × 2 factorial (6 replicate pens per treatment). The main effects were dietary L-carnitine (0 or 50 mg/kg), RAC (0 or 10 mg/kg), and added choice white grease (0 or 6%). Pigs were fed a corn-soybean meal-based diet (Table 1) with or without added L-carnitine and with or without added fat from 44 kg until slaughter (approximately 118 kg), whereas RAC was

**Table 1.** Basal diet composition (as-fed basis)[1]

| | Exp. 1[2] | | Exp. 2[3] | Exp. 3[4] | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 44 | | 61 | | 92 | |
| Item Initial BW, kg: | 33 | 74 | 87 | No fat | Fat | No fat | Fat | No fat | Fat |
| Ingredient, % | | | | | | | | | |
| Corn | 68.41 | 74.50 | 74.50 | 73.00 | 63.30 | 78.60 | 69.35 | 75.10 | 65.55 |
| Soybean meal, 46.5% CP | 26.63 | 22.80 | 22.80 | 24.60 | 28.25 | 19.15 | 22.35 | 22.75 | 26.25 |
| Choice white grease | – | – | – | – | 6.00 | – | 6.00 | – | 6.00 |
| Soybean oil | 2.00 | – | – | – | – | – | – | – | – |
| Monocalcium phosphate, 21% P | 1.05 | 0.90 | 0.90 | 0.85 | 0.94 | 0.73 | 0.80 | 0.64 | 0.70 |
| Limestone | 1.00 | 0.90 | 0.90 | 0.88 | 0.84 | 0.85 | 0.83 | 0.84 | 0.81 |
| Salt | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| Vitamin premix [5] | 0.15 | 0.15 | 0.15 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |
| Trace mineral premix [6] | 0.15 | 0.15 | 0.15 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| L-lysine HCl | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| Medication [7] | 0.05 | – | – | – | – | – | – | – | – |
| DL-methionine | 0.01 | – | – | – | – | – | – | – | – |
| Cornstarch | 0.05 | 0.10 | 0.10 | – | – | – | – | – | – |
| Calculated composition, % | | | | | | | | | |
| CP (N × 6.25) | 18.20 | 16.90 | 16.90 | 17.60 | 18.50 | 15.60 | 16.30 | 17.00 | 17.80 |
| Total Lys | 1.10 | 1.00 | 1.00 | 1.05 | 1.14 | 0.90 | 0.97 | 1.00 | 1.08 |
| Lys:ME ratio, g/Mcal | 3.24 | 3.01 | 3.01 | 3.16 | 3.16 | 2.70 | 2.70 | 3.00 | 3.00 |
| ME, kcal/kg | 3399 | 3318 | 3318 | 3327 | 3596 | 3336 | 3605 | 3338 | 3607 |
| Ca | 0.69 | 0.61 | 0.61 | 0.60 | 0.61 | 0.55 | 0.56 | 0.54 | 0.55 |
| P | 0.60 | 0.55 | 0.55 | 0.55 | 0.57 | 0.50 | 0.52 | 0.50 | 0.51 |

[1]Diets were formulated to meet or exceed NRC (1998) requirements.

[2]L-carnitine replaced cornstarch to provide 0, 25, or 50 mg/kg L-carnitine. Ractopamine HCl (RAC; Elanco Animal Health, Greenfield, IN) replaced cornstarch to provide 0, 5, or 10 mg/kg RAC.

[3]L-carnitine replaced cornstarch to provide starch 0, 25, or 50 mg/kg L-carnitine. Ractopamine HCl replaced cornstarch to provide 0 or 10 mg/kg RAC.

[4]L-carnitine replaced corn to provide 0, or 50 mg/kg L-carnitine. Ractopamine HCl replaced corn to provide 0 or 10 mg/kg RAC.

[5]In Exp. 1 and 2, vitamin premix provided (per kilogram of complete diet): vitamin A, 6614 IU; vitamin $D_3$, 992 IU; vitamin E, 26.5 IU; menadione (menadione dimethylpyrimidinol bisulphite), 2.65; vitamin $B_{12}$, 0.03 mg; riboflavin, 5.95 mg; pantothenic acid, 19.8 mg; and niacin, 33.1 mg. In Exp. 3, vitamin premix provided (per kilogram of complete diet): vitamin A, 7937 USP; vitamin $D_3$, 1190 USP; vitamin E, 31.75 IU, vitamin $B_{12}$, 0.03 mg; riboflavin, 7.14 mg; pantothenic acid, 23.81 mg; niacin, 39.68 mg.

[6]In Exp. 1 and 2, trace mineral premix provided (per kilogram of complete diet): Mn (from manganese oxide), 39.7 mg; Fe (from ferrous sulfate), 165.3 mg; Zn (from zinc oxide) 165.3 mg; Cu (from copper sulfate), 16.5 mg; I (from calcium iodate) 0.3 mg; and Se (from sodium selenite), 0.3 mg. In Exp. 3, trace mineral premix provided (per kilogram of complete diet): Mn (from manganese oxide), 35.7 mg; Fe (from ferrous sulfate), 148.8 mg; Zn (from zinc oxide), 148.8 mg; Cu (from copper sulfate), 14.9 mg; I (from calcium iodate) 0.3 mg; and Se (from sodium selenite) 0.3 mg.

[7]Provided 44 mg tylosin per kilogram diet.

fed for the last 4 wk of the experiment. Basal diets were formulated on a total Lys:calorie ratio-basis, with ratios of 3.16, 2.70, and 3.00 g Lys/Mcal ME from 44.0 to 61.2 (phase 1), 61.2 to 92.1 (phase 2), and 92.1 to 118 kg (phase 3). Corresponding total Lys in the 0 and 6% added fat diets were 1.05 and 1.14% (17.6 and 18.5% CP), 0.90 and 0.97% (15.6 and 16.3% CP), and 1.00 and 1.08% (17.0 and 17.8% CP) for dietary phases 1, 2, and 3, respectively.

At the end of the feeding trial, 8 pigs were randomly selected from each pen and slaughtered at a commercial facility (JBS; Swift, Inc., Worthington, MN). Carcass weight, as well as fat and LM depths, were recorded before chilling. Midline backfat depth at the first rib, last rib, and last lumbar vertebrae were measured 24 h postmortem. Then left carcass sides were ribbed between the 10th and 11th rib and 10th rib fat thickness and LM area were measured before ultimate (24-h) LM pH was measured with an Accument Portable pH Probe (Model AP61; Fischer Scientific, Pittsburgh, PA). In addition, subjective LM firmness, marbling, and color along with instrumental color (L*, a*, and b*) values were subsequently measured on the exposed LM at the 10th rib. Lastly, LM drip loss percentage was measured at 24 h postmortem according to both the filter paper method and suspension method of Kauffman et al. (1986).

### *Statistical Analyses*

Data from all experiments were analyzed as a randomized complete block design using the mixed models procedure (SAS Inst. Inc., Cary, NC) with pen as the experimental unit for carcass characteristics and meat quality measurements. Linear and quadratic polynomial contrasts were used to determine the effects of L-carnitine level (Exp. 1) and RAC level (Exp. 1 and 2). Hot carcass weight was used as a covariate in the statistical analysis of backfat, carcass length, LM area, and percentage lean. Statistical significance and tendencies were set at $P \leq 0.05$ and $P < 0.10$ for all statistical tests, respectively. When a significant ($P \leq 0.05$) treatment effect was realized, least squares means were separated with pairwise *t* tests (PDIFF option of SAS).

## RESULTS

### *Experiment 1*

There were no RAC × L-carnitine interactions ($P > 0.10$) for carcass characteristics (Table 2). Dressing percentage tended to increase (linear, $P < 0.06$) and carcass shrink decreased (quadratic, $P < 0.05$) with increasing dietary RAC. Even though average backfat, as well as fat depth opposite the first rib, last rib, and last lumbar vertebra were not affected ($P < 0.10$) by dietary L-carnitine or RAC, 10th rib fat thickness tended to increase with increasing dietary RAC (linear, $P = 0.10$) and L-carnitine (linear, $P = 0.07$). In addition, increasing RAC tended to increase (quadratic, $P < 0.10$) LM area and lean yield.

There was a RAC × L-carnitine interaction ($P < 0.02$) for visual color, L*, a*/b* ratio, and hue angle (Table 3). The LM was darker (lower L* values) in pigs fed increasing L-carnitine when 5 or 10 mg/kg RAC was included in the diet but became lighter in pigs not fed RAC. Adding L-carnitine to diets containing 5 or 10 mg/kg RAC increased a*/b* and decreased hue angle values indicating a more red color. There was a

**Table 2.** Carcass characteristics of finishing pigs fed L-carnitine and ractopamine HCl (RAC; Elanco Animal Health, Greenfield, IN; Exp. 1)[1,2]

| | RAC, mg/kg | | | | | | | | | | Probability, *P* < | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | 5 | | | 10 | | | | | RAC | | L-carnitine | |
| | L-carnitine, mg/kg | | | | | | | | | | RAC × | | | | |
| Item | 0 | 25 | 50 | 0 | 25 | 50 | 0 | 25 | 50 | SED | L-carnitine | Linear | Quadratic | Linear | Quadratic |
| Dressing, % | 72.99 | 73.39 | 73.40 | 74.19 | 74.26 | 73.68 | 75.18 | 73.40 | 73.63 | 0.57 | 0.14 | 0.06 | 0.25 | 0.21 | 0.64 |
| Shrink loss[3], % | 2.15 | 2.12 | 2.13 | 2.15 | 2.64 | 2.08 | 1.32 | 2.01 | 1.96 | 0.40 | 0.69 | 0.53 | 0.05 | 0.45 | 0.24 |
| Backfat, cm | | | | | | | | | | | | | | | |
| first rib | 3.95 | 3.63 | 3.82 | 3.69 | 3.67 | 3.73 | 3.62 | 3.66 | 3.50 | 0.25 | 0.87 | 0.55 | 0.32 | 0.65 | 0.67 |
| 10th rib | 1.69 | 1.45 | 1.52 | 1.44 | 1.40 | 1.35 | 1.47 | 1.45 | 1.18 | 0.14 | 0.64 | 0.10 | 0.22 | 0.07 | 0.96 |
| Last rib | 2.55 | 2.45 | 2.39 | 2.31 | 2.49 | 2.42 | 2.63 | 2.45 | 2.27 | 0.16 | 0.60 | 0.61 | 0.85 | 0.23 | 0.70 |
| Last lumbar vertebra | 1.74 | 1.63 | 1.71 | 1.53 | 1.41 | 1.69 | 1.53 | 1.45 | 1.53 | 0.16 | 0.94 | 0.16 | 0.27 | 0.77 | 0.21 |
| Average | 2.75 | 2.57 | 2.64 | 2.51 | 2.52 | 2.62 | 2.60 | 2.53 | 2.43 | 0.17 | 0.86 | 0.34 | 0.45 | 0.55 | 0.63 |
| Carcass length, cm | 80.04 | 80.16 | 79.60 | 80.65 | 79.54 | 79.84 | 79.10 | 79.51 | 79.92 | 0.70 | 0.53 | 0.85 | 0.29 | 0.80 | 0.77 |
| LM area, $cm^2$ | 43.94 | 45.83 | 42.60 | 44.44 | 44.75 | 46.05 | 46.90 | 47.09 | 46.94 | 2.47 | 0.88 | 0.62 | 0.10 | 0.99 | 0.57 |
| Lean, % | 56.17 | 58.04 | 56.56 | 57.47 | 57.96 | 58.50 | 58.30 | 59.72 | 59.72 | 1.31 | 0.78 | 0.26 | 0.09 | 0.31 | 0.64 |

[1]Values are means of 7 or 5 replications (pig closest to 118 kg in each pen). Pigs were fed a corn-soybean meal diet with added L-carnitine (0, 25, or 50 mg/kg) from 33.4 kg until the end of the experiment (approximately 109 kg). Dietary RAC treatments (0, 5, or 10 mg/kg) were fed for the last 4 wk of the experiment.

[2]HCW was used as a covariate in the statistical analysis except for dressing (%) and shrink loss (%).

[3]Shrink loss was calculated as 1- (cold carcass weight/HCW) × 100.

RAC × L-carnitine interaction observed for marbling ($P = 0.08$), a* ($P = 0.08$), and LM 45-min pH ($P = 0.10$). Increasing L-carnitine decreased marbling and redness (lower a* values) when RAC was not in the diet, but increased marbling and redness when diets contained 5 or 10 mg/kg RAC. Longissimus muscle 45-min pH increased with increasing L-carnitine in diets without RAC, but 45-min pH was unchanged with increasing L-carnitine in diets containing 5 or 10 mg/kg RAC.

Both b* value and saturation index decreased (quadratic, $P < 0.07$) with increasing L-carnitine in the diet. Drip loss percentage (linear, $P < 0.04$) and LM temperature at 45 min postmortem (linear, $P < 0.01$) decreased with increasing L-carnitine. Ultimate (24-h) LM pH increased (linear, $P < 0.07$) with increasing L-carnitine in the diet. Furthermore, ultimate pH tended to increase (quadratic, $P < 0.06$) and as RAC increased, drip loss percentage tended (quadratic, $P < 0.09$) to decrease then return to values similar to that of pigs fed no RAC.

### *Experiment 2*

There was a RAC × L-carnitine interaction ($P < 0.01$) for dressing percentage (Table 4). Dressing percentage was greater in pigs fed 25 mg/kg L-carnitine than for pigs fed 0 or 50 mg/kg when no RAC was included in the diet, but dressing percentage was actually less in pigs fed 25 mg/kg L-carnitine than those fed 0 or 50 mg/kg when pigs consumed diets with 10 mg/kg RAC.

Conversely, there were no RAC × L-carnitine interactions ($P > 0.10$) observed for shrink loss, any external fat measurement, carcass length, LM area, or lean yield. Although carcasses from pigs fed RAC had greater ($P < 0.01$) lean yields than pigs not fed RAC, there was no effect of RAC on carcass dressing percentage, shrink, length, LM area, or any fat measurement. As dietary L-carnitine increased, first rib, 10th rib, and average fat depth, tended to decrease (linear, $P < 0.10$) and lean yields tended to increase (linear, $P < 0.10$)

There was a RAC × L-carnitine interaction ($P < 0.04$) observed for visual firmness, percentage drip loss, percentage transmission, and temperature measured 1.5 h postmortem (Table 5). Visual firmness scores decreased when pigs were fed increasing L-carnitine and no RAC but increased with increasing L-carnitine when RAC was in the diet. Moreover, drip loss percentages and transmission value decreased with increasing L-carnitine when it was fed in combination with RAC. Even though there were no RAC × L-carnitine interactions ($P > 0.10$) for LM pH measured at any time postmortem, LM temperatures were lower at 1.5 and 3 h postmortem when RAC pigs were fed increasing L-carnitine (RAC × L-carnitine, $P < 0.10$). Visual color scores were less ($P < 0.02$) and L* values greater ($P < 0.01$) in the LM of RAC-fed pigs (Table 5). Moreover, the LM from RAC fed pigs was less red than the LM from pigs fed 0 mg/kg RAC, as indicated by the lower a* values ($P < 0.07$), a*/b* ratios ($P < 0.01$), and greater hue angles ($P < 0.01$). In addition, LM pH measured at 3

**Table 3.** Carcass quality measures of finishing pigs fed L-carnitine and ractopamine HCl (RAC; Elanco Animal Health, Greenfield, IN; Exp 1)[1]

| | RAC, mg/kg | | | | | | | | | | Probability, $P <$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | 5 | | | 10 | | | | | | | | |
| | L-carnitine, mg/kg | | | | | | | | | | RAC × | RAC | | L-carnitine | |
| Item | 0 | 25 | 50 | 0 | 25 | 50 | 0 | 25 | 50 | SED | L-carnitine | Linear | Quadratic | Linear | Quadratic |
| Visual color[2] | 3.35 | 2.78 | 3.14 | 2.57 | 3.28 | 3.49 | 2.57 | 3.00 | 2.85 | 0.25 | 0.02 | 0.99 | 0.08 | 0.11 | 0.82 |
| Firmness[2] | 1.93 | 1.65 | 1.93 | 1.79 | 1.93 | 2.05 | 1.79 | 2.15 | 1.79 | 0.24 | 0.43 | 0.66 | 0.81 | 0.66 | 0.81 |
| Marbling[2] | 2.00 | 1.71 | 1.85 | 1.35 | 2.07 | 1.82 | 1.64 | 2.00 | 1.71 | 0.21 | 0.08 | 0.46 | 0.91 | 0.42 | 0.13 |
| Lightness[3] (L*) | 55.37 | 58.01 | 56.80 | 60.78 | 56.39 | 55.06 | 61.53 | 58.46 | 57.88 | 1.25 | 0.01 | 0.41 | 0.01 | 0.01 | 0.68 |
| Redness[3] (a*) | 7.61 | 6.17 | 6.45 | 5.78 | 6.22 | 7.00 | 6.30 | 6.71 | 6.51 | 0.53 | 0.08 | 0.23 | 0.99 | 0.94 | 0.52 |
| Yellowness[3] (b*) | 15.25 | 14.61 | 15.10 | 15.69 | 14.09 | 14.19 | 15.9 | 14.98 | 15.04 | 0.53 | 0.67 | 0.42 | 0.14 | 0.03 | 0.05 |
| a*/b*[3] | 0.50 | 0.42 | 0.43 | 0.37 | 0.44 | 0.50 | 0.39 | 0.45 | 0.43 | 0.03 | 0.01 | 0.42 | 0.49 | 0.27 | 0.9 |
| Hue angle | 63.60 | 67.38 | 67.05 | 69.95 | 66.31 | 63.71 | 68.65 | 65.91 | 66.69 | 1.44 | 0.01 | 0.44 | 0.52 | 0.25 | 0.84 |
| Saturation index[3] | 17.06 | 15.89 | 16.44 | 16.76 | 15.42 | 15.84 | 17.12 | 16.43 | 16.41 | 0.64 | 0.97 | 0.30 | 0.26 | 0.09 | 0.07 |
| Drip loss, % | 2.68 | 2.80 | 2.07 | 3.13 | 1.48 | 1.49 | 3.68 | 2.29 | 2.94 | 0.66 | 0.47 | 0.33 | 0.09 | 0.04 | 0.22 |
| Temperature, °C | 34.72 | 34.83 | 32.98 | 34.39 | 34.38 | 33.80 | 35.72 | 34.15 | 33.76 | 0.83 | 0.6 | 0.97 | 0.44 | 0.01 | 0.62 |
| LM pH | | | | | | | | | | | | | | | |
| 45 min postmortem | 6.22 | 6.55 | 6.46 | 6.41 | 6.44 | 6.34 | 6.33 | 6.23 | 6.39 | 0.10 | 0.10 | 0.99 | 0.17 | 0.24 | 0.49 |
| 24 h postmortem | 5.75 | 5.79 | 5.76 | 5.79 | 5.86 | 5.86 | 5.71 | 5.79 | 5.78 | 0.04 | 0.91 | 0.01 | 0.06 | 0.07 | 0.08 |

[1]Values are means of 7 or 5 replications (pig closest to 118 kg in each pen). Pigs were fed a corn-soybean meal diet with added L-carnitine (0, 25, or 50 mg/kg) from 33.4 kg until the end of the experiment (approximately 109 kg). Dietary RAC treatments (0, 5, or 10 mg/kg) were fed for the last 4 wk of the experiment.

[2]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, firmness, and marbling, respectively.

[3]Means were derived from 2 sample readings per loin. Measures of dark to light (L*), redness (a*), yellowness (b*), red to orange (hue angle), and vividness or intensity (saturation index).

**Table 4.** Carcass characteristics of finishing pigs fed L-carnitine and ractopamine HCl (RAC; Elanco Animal Health, Greenfield, IN; Exp. 2)[1,2]

| | RAC, mg/kg (RAC) | | | | | | | Probability, $P <$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | 10 | | | | | | | |
| | L-carnitine, mg/kg | | | | | | | RAC × | | L-carnitine | |
| Item | 0 | 25 | 50 | 0 | 25 | 50 | SED | L-carnitine | RAC | Linear | Quadratic |
| Dressing, % | 72.30 | 74.48 | 72.71 | 74.90 | 73.56 | 74.25 | 0.39 | 0.01 | 0.35 | 0.79 | 0.23 |
| Shrink loss[3], % | 2.27 | 1.72 | 1.73 | 1.76 | 1.79 | 1.74 | 0.24 | 0.41 | 0.46 | 0.24 | 0.56 |
| Backfat, cm | | | | | | | | | | | |
| First rib | 3.57 | 3.58 | 3.16 | 3.62 | 3.77 | 3.42 | 0.18 | 0.83 | 0.25 | 0.09 | 0.14 |
| 10th rib | 1.73 | 1.65 | 1.60 | 1.69 | 1.60 | 1.43 | 0.11 | 0.77 | 0.30 | 0.06 | 0.86 |
| Last rib | 2.06 | 2.10 | 2.02 | 2.27 | 1.98 | 2.00 | 0.14 | 0.47 | 0.84 | 0.24 | 0.70 |
| Last lumbar vertebra | 1.84 | 1.66 | 1.74 | 1.80 | 1.66 | 1.49 | 0.13 | 0.85 | 0.35 | 0.11 | 0.63 |
| Average | 2.49 | 2.44 | 2.30 | 2.56 | 2.46 | 2.30 | 0.12 | 0.96 | 0.76 | 0.07 | 0.73 |
| Carcass length, cm | 82.94 | 83.38 | 82.68 | 82.88 | 83.00 | 82.94 | 0.66 | 0.89 | 0.90 | 0.88 | 0.55 |
| LM area, $cm^2$ | 42.56 | 45.76 | 43.40 | 50.40 | 46.50 | 50.98 | 1.47 | 0.94 | 0.76 | 0.65 | 0.60 |
| Lean, % | 54.85 | 55.50 | 55.80 | 56.71 | 56.19 | 58.09 | 0.71 | 0.50 | 0.01 | 0.10 | 0.40 |

[1]Values are means of 10 replications (1 pig selected randomly from each pen). Pigs were fed a corn-soybean meal basal diet with added L-carnitine (0, 25, or 50 mg/kg) and RAC (0 or 10 mg/kg) for the 4-wk experiment.

[2]HCW was used as a covariate in the statistical analysis except for dressing (%) and shrink loss (%).

[3]Shrink loss was calculated as 1- (cold carcass weight/HCW) × 100.

and 6 h postmortem was less ($P < 0.06$) when pigs were fed 10 mg/kg RAC, but ultimate (24-h) pH values were not ($P > 0.10$) affected by dietary RAC. Feeding L-carnitine did not affect ($P > 0.10$) other measured carcass characteristics.

### *Experiment 3*

There was a L-carnitine × RAC × fat interaction ($P < 0.04$) for LM area (Table 6). In general, adding RAC, L-carnitine, or choice white grease to the diet increased LM area; however, the responses were not entirely additive, which led to the interaction.

There was an L-carnitine × RAC interaction ($P < 0.03$) for fat thickness and carcass lean yield. Fat depth at the first and 10th ribs decreased, and LM depth and carcass lean yield increased, in carcasses of pigs fed L-carnitine and RAC, but the interactive responses ($P < 0.09$) were not additive. In addition, feeding 10 mg/kg RAC tended to decrease average backfat depth in pigs fed choice white grease (RAC × choice white grease interaction, $P = 0.09$). Carcasses of pigs fed L-carnitine were heavier ($P < 0.07$) and leaner ($P < 0.02$) at the first rib than carcasses of pigs fed no L-carnitine. Moreover, 10th rib fat thickness, last lumbar vertebra fat depth, and average backfat depth were reduced ($P < 0.03$) in RAC-fed pigs. Conversely, adding 6% choice white grease increased ($P < 0.01$) carcass weight and fat depths opposite the first, 10th, and last ribs and last lumbar vertebra, as well as average backfat depth, and decreased ($P < 0.01$) LM depth and carcass lean percentage.

There were no RAC × L-carnitine × choice white grease interactions observed ($P > 0.10$) for any of the pork quality measures (Table 7). The LM from pigs fed L-carnitine and no added fat had greater visual firmness scores than pigs fed L-carnitine with 6% added choice white grease (L-carnitine × choice white grease interaction; $P = 0.04$). Including 50 mg/kg of L-carnitine tended ($P = 0.10$) to increase LM lightness (L*) values and decrease ($P = 0.04$) drip loss percentages as measured by the suspension method. Both ultimate pH and visual firmness of the LM were increased ($P \leq 0.04$) by feeding 10 mg/kg RAC. Moreover, dietary RAC reduced ($P < 0.01$) a* and drip losses as measured by the filter paper method. On the other hand, feeding 6% choice white grease increased ($P \leq 0.03$) both a* and b* values. Filter-paper-measured drip loss percentages were also increased ($P < 0.02$) by the addition of 6% choice white grease to the diet.

## DISCUSSION

### *Carcass Measurements*

In previous studies, improvements in dressing percentage ranged from 0.3 to 2.0% for pigs fed 5 mg/kg RAC (Stites et al., 1991; See et al., 2005) and from 0.7 to 2.2% for pigs fed 10 mg/kg RAC (Watkins et al., 1990; See et al., 2005; Apple et al., 2007) compared with pigs not fed RAC. Results of the current studies showed similar improvement. Adding L-carnitine to finishing diets had no appreciable effects on dressing percentage, which is similar to the findings of Pietruszka et al. (2009), who reported similar dressing percentages when 0 or 100 mg/kg L-carnitine were added to finishing pig diets.

Effects of dietary RAC on LM area were consistent across the current 3 experiments. In Exp. 1, LM area

**Table 5.** Carcass characteristics of finishing pigs fed L-carnitine and ractopamine HCl (RAC; Elanco Animal Health, Greenfield, IN; Exp. 2)[1]

| | RAC, mg/kg | | | | | | | Probability, $P <$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | 10 | | | | | | | |
| | L-carnitine, mg/kg | | | | | | | RAC × | | L-carnitine | |
| Item | 0 | 25 | 50 | 0 | 25 | 50 | SED | L-carnitine | RAC | Linear | Quadratic |
| Blood | | | | | | | | | | | |
| Glucose, mg/dL | 109.73 | 107.07 | 108.44 | 109.21 | 103.82 | 108.89 | 3.74 | 0.88 | 0.71 | 0.83 | 0.26 |
| Lactate, mmol/L | 12.46 | 11.78 | 10.41 | 11.71 | 9.93 | 10.36 | 1.51 | 0.84 | 0.47 | 0.26 | 0.77 |
| pH | 7.14 | 7.13 | 7.21 | 7.16 | 7.16 | 7.21 | 0.05 | 0.94 | 0.76 | 0.23 | 0.47 |
| Temperature, °C | | | | | | | | | | | |
| 5 min postmortem | 38.59 | 39.79 | 39.17 | 39.6 | 39.74 | 39.68 | 0.56 | 0.60 | 0.24 | 0.51 | 0.25 |
| 15 min postmortem | 40.20 | 39.92 | 39.56 | 40.42 | 40.18 | 40.06 | 0.31 | 0.88 | 0.16 | 0.09 | 0.97 |
| 45 min postmortem | 37.72 | 39.03 | 38.73 | 39.43 | 38.35 | 38.76 | 0.69 | 0.18 | 0.16 | 0.73 | 0.93 |
| 1.5 h postmortem | 32.91 | 32.87 | 33.17 | 35.99 | 33.51 | 32.65 | 0.72 | 0.04 | 0.06 | 0.05 | 0.46 |
| 3 h postmortem | 21.38 | 22.12 | 20.89 | 24.38 | 22.37 | 22.76 | 0.63 | 0.10 | 0.01 | 0.11 | 0.85 |
| 6 h postmortem | 10.74 | 11.28 | 11.22 | 12.04 | 11.09 | 10.97 | 0.48 | 0.20 | 0.47 | 0.55 | 0.89 |
| LM pH | | | | | | | | | | | |
| 5 min postmortem | 6.93 | 6.84 | 6.82 | 6.79 | 6.80 | 6.94 | 0.07 | 0.17 | 0.76 | 0.74 | 0.40 |
| 15 min postmortem | 6.55 | 6.60 | 6.58 | 6.59 | 6.47 | 6.49 | 0.07 | 0.48 | 0.35 | 0.62 | 0.76 |
| 45 min postmortem | 6.16 | 6.16 | 6.02 | 6.14 | 6.21 | 6.13 | 0.10 | 0.82 | 0.57 | 0.44 | 0.43 |
| 1.5 h postmortem | 5.95 | 5.91 | 5.97 | 5.89 | 5.95 | 5.92 | 0.10 | 0.87 | 0.74 | 0.77 | 0.94 |
| 3 h postmortem | 5.77 | 5.76 | 5.88 | 5.59 | 5.67 | 5.69 | 0.08 | 0.77 | 0.01 | 0.15 | 0.73 |
| 6 h postmortem | 5.76 | 5.70 | 5.70 | 5.61 | 5.66 | 5.68 | 0.04 | 0.23 | 0.06 | 0.90 | 0.89 |
| 24 h postmortem | 5.64 | 5.61 | 5.60 | 5.58 | 5.64 | 5.59 | 0.02 | 0.19 | 0.57 | 0.60 | 0.26 |
| Visual color[2] | 3.20 | 3.10 | 2.90 | 2.75 | 2.75 | 2.80 | 0.16 | 0.52 | 0.02 | 0.93 | 0.43 |
| Firmness[2] | 2.59 | 2.44 | 2.34 | 1.99 | 2.59 | 2.34 | 0.15 | 0.04 | 0.25 | 0.75 | 0.15 |
| Marbling[2] | 1.65 | 1.75 | 1.55 | 1.85 | 1.75 | 1.60 | 0.18 | 0.85 | 0.57 | 0.33 | 0.57 |
| Lightness[3] (L*) | 57.18 | 57.23 | 58.00 | 59.72 | 59.63 | 58.44 | 0.83 | 0.37 | 0.01 | 0.78 | 0.89 |
| Redness[3] (a*) | 7.54 | 7.58 | 7.93 | 7.94 | 6.73 | 6.61 | 0.38 | 0.07 | 0.07 | 0.24 | 0.30 |
| Yellowness[3] (b*) | 15.81 | 15.86 | 16.27 | 16.97 | 15.75 | 15.29 | 0.47 | 0.08 | 0.95 | 0.22 | 0.51 |
| a*/b*[3] | 0.48 | 0.48 | 0.49 | 0.46 | 0.43 | 0.43 | 0.02 | 0.40 | 0.01 | 0.46 | 0.30 |
| Hue angle[3] | 64.49 | 64.61 | 64.07 | 65.14 | 66.99 | 66.70 | 0.78 | 0.39 | 0.01 | 0.47 | 0.30 |
| Saturation index[3] | 17.52 | 17.59 | 18.11 | 18.74 | 17.13 | 16.67 | 0.56 | 0.06 | 0.64 | 0.20 | 0.42 |
| Drip loss, % | 2.04 | 3.07 | 2.73 | 4.85 | 2.47 | 2.82 | 0.64 | 0.02 | 0.48 | 0.32 | 0.56 |
| Transmission, % | 50.40 | 53.09 | 60.00 | 66.69 | 49.85 | 58.27 | 3.52 | 0.01 | 0.19 | 0.87 | 0.02 |

[1]Values are means of 10 replications (1 pig selected randomly from each pen). Pigs were fed a corn-soybean meal basal diet with added L-carnitine (0, 25, or 50 mg/kg) and RAC (0 or 10 mg/kg) for the 4-wk experiment.

[2]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, firmness, and marbling, respectively.

[3]Means were derived from 2 sample readings per loin. Measures of dark to light (L*), redness (a*), yellowness (b*), red to orange (hue angle), and vividness or intensity (saturation index).

increased by 1.0 and 2.9 $cm^2$ for pigs fed diets containing 5 and 10 mg/kg RAC, respectively, compared with pigs not fed RAC, whereas feeding 10 mg/kg RAC to finishing pigs increased LM area by 5.4 and 2.2 $cm^2$ in Exp. 2 and 3, respectively. These improvements were within the range (1.4 to 7.3 $cm^2$) of increases in LM area observed in other studies in which finishing pigs fed 10 mg/kg RAC were compared with untreated controls (Crome et al., 1996; Stoller et al., 2003; Armstrong et al., 2004). In addition, the meta-analysis of Apple et al. (2007) observed that feeding 5 or 10 mg/kg RAC increased LM area of finishing pigs by 2.3 and 3.5 $cm^2$, respectively.

The effect of RAC feeding on 10th rib and average backfat depths was inconsistent across the present experiments. There were no differences in backfat depth in Exp. 1 and 2, but in Exp. 3, pigs fed 10 mg/kg RAC had less fat opposite the first rib, 10th rib, last lumbar vertebra, and average backfat depth compared with pigs not fed RAC. Researchers initially thought that feeding RAC limited fat accretion, but the effects of RAC on 10th rib fat depth have been conflicting. Several studies have shown that pigs fed 10 mg/kg RAC have 6 to 16% less fat at the 10th rib than pigs not fed RAC (Apple et al., 2004a, 2008; Carr et al., 2005b). One item potentially explaining the variability in our results could be the difference in level of feed (energy) intake between the studies conducted with 2 pigs per pen compared with the pigs housed in the commercial facility (James et al., 2013). Pigs in Exp. 1

**Table 6.** Interactive effects of L-carnitine, ractopamine HCl (RAC; Elanco Animal Health, Greenfield, IN), and fat on carcass characteristics (Exp. 3)[1]

| | Fat, % | | | | | | | | | Probability, $P <$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | | 6 | | | | | | | | | | | |
| | L-carnitine, mg/kg | | | | | | | | | | | | | | | |
| | 0 | | 50 | | 0 | | 50 | | | | | | | | | |
| | RAC, mg/kg | | | | | | | | | | | | | | | |
| Item | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | SED | RAC × L-carnitine × Fat | RAC × L-carnitine | L-carnitine × Fat | RAC × Fat | L-carnitine | RAC | Fat |
| Carcass wt, kg | 89.8 | 91.3 | 90.8 | 92.2 | 92.3 | 93.9 | 95.2 | 95.1 | 1.19 | 0.64 | 0.53 | 0.48 | 0.67 | 0.07 | 0.19 | 0.01 |
| Fat thickness[2], mm | 16.76 | 13.92 | 16.29 | 14.72 | 18.83 | 16.09 | 16.77 | 16.25 | 0.56 | 0.54 | 0.03 | 0.16 | 0.47 | 0.32 | 0.01 | 0.01 |
| Loin depth[2], mm | 59.28 | 62.80 | 60.89 | 61.52 | 57.93 | 61.11 | 59.16 | 60.65 | 0.81 | 0.68 | 0.06 | 0.94 | 0.91 | 0.54 | 0.01 | 0.01 |
| Lean,% | 56.15 | 59.19 | 56.82 | 58.29 | 54.12 | 57.03 | 56.13 | 56.82 | 0.59 | 0.67 | 0.02 | 0.23 | 0.56 | 0.33 | 0.01 | 0.01 |
| LM area, $cm^2$ | 47.34 | 48.59 | 48.47 | 50.25 | 47.24 | 51.33 | 52.09 | 50.48 | 1.10 | 0.04 | 0.09 | 0.69 | 0.85 | 0.03 | 0.07 | 0.03 |
| Backfat, cm | | | | | | | | | | | | | | | | |
| First rib | 3.58 | 3.49 | 3.57 | 3.49 | 3.91 | 3.62 | 3.57 | 3.66 | 0.08 | 0.13 | 0.09 | 0.22 | 0.89 | 0.19 | 0.11 | 0.01 |
| 10th rib | 1.67 | 1.58 | 1.69 | 1.63 | 1.74 | 1.65 | 1.64 | 1.64 | 0.04 | 0.53 | 0.29 | 0.12 | 0.53 | 0.70 | 0.03 | 0.47 |
| Last rib | 2.68 | 2.53 | 2.70 | 2.67 | 2.84 | 2.76 | 2.81 | 2.82 | 0.07 | 0.89 | 0.30 | 0.49 | 0.57 | 0.36 | 0.18 | 0.01 |
| Last lumbar vertebra | 1.55 | 1.41 | 1.51 | 1.39 | 1.70 | 1.60 | 1.53 | 1.46 | 0.06 | 0.93 | 0.74 | 0.11 | 0.54 | 0.02 | 0.01 | 0.01 |
| Average backfat | 2.61 | 2.48 | 2.60 | 2.52 | 2.81 | 2.66 | 2.64 | 2.63 | 0.05 | 0.51 | 0.17 | 0.09 | 0.72 | 0.19 | 0.01 | 0.01 |

[1]Values are means of 6 replications (pens) and 8 pigs per pen. Pigs were fed a corn-soybean meal diet with added L-carnitine (0 or 50 mg/kg) or added fat (0 or 6%) from 44.0 kg until slaughter (approximately 118 kg). Dietary RAC (0 or 10 mg/kg) was fed for the last 4 wk of the experiment.

[2]Measurements were determined with Ultrafom (UFOM) and collected 7 cm off the midline at the 10th rib; lean percentage was calculated with these values.

and 2 consumed approximately 0.2 to 0.5 kg more feed per day than pigs in Exp. 3; hence, the greater feed intake likely exceeded their requirement for protein deposition, whereas the pigs in the commercial environment might have still been in an energy-dependent stage of growth.

Previous studies suggested that added dietary L-carnitine could increase body L-carnitine status and positively affect use of fatty acids as energy-yielding compounds, which may lead to increased accretion of body protein and reduced carcass fat (Harmeyer, 2003). Dietary L-carnitine did not affect LM area, LM depth, or carcass lean yields nor did it affect 10th rib and average backfat in the present studies. However, Owen et al. (2001) demonstrated a linear increase in percentage lean and muscle and a linear decrease in 10th rib fat thickness as dietary L-carnitine increased in pigs from 56 to 120 kg. Likewise, Rekiel and Zackiewicz (2004) reported that pigs fed diets with 50 mg/kg added L-carnitine had greater carcass meatiness and observed a reduction in backfat. Chen et al. (2008) reported greater percentage of carcass lean when pigs were fed 250 mg/kg L-carnitine even though they did not find any improvements in LM area. Heo et al. (2000b) reported that adding 500 mg/kg L-carnitine reduced lipid accretion. However, Pietruszka et al. (2009) failed to detect an effect of 100 mg/kg of dietary L-carnitine on LM weight or area and the percentage lean.

It was hypothesized that responses from the added L-carnitine might increase in pigs fed diets with high fat levels, but no carcass fatness measurements were affected by feeding increased choice white grease and L-carnitine. It was also thought that adding L-carnitine to a finishing diet with RAC could enhance the efficiency of transport and use of fatty acids for energy production as well as the effects attributed to RAC, especially when diets have added fat. In general, the current study showed that adding RAC, L-carnitine, or fat to the diet increased LM area; however, responses were not entirely additive, which led to the interaction.

### *Pork Quality Measurements*

Pork color is an important quality characteristic affecting consumer perceptions of freshness at the point of purchase and exportability of fresh pork products (Apple et al., 2007). Feeding RAC did not change visual pork color in Exp. 1 and 3, but, in Exp. 2, feeding 10 mg/kg RAC negatively affected visual color. Most previous studies have shown that feeding pigs 10 mg/kg RAC had no detrimental effects on visual color scores (Carr et al., 2005a,b; Rincker et al., 2005). In Exp. 1, L-carnitine improved visual color scores when 5 or 10 mg/kg RAC was fed but did not affect visual color in control pigs. Trapp et al. (2002) fed 50 mg/kg L-carnitine and 5 mg/kg RAC to finishing pigs and observed increased visual color scores (i.e., darker colored meat), and Owen et al. (2001) observed that increasing dietary L-carnitine increased LM visual color scores as well.

Most packers measure and sort pork on the basis of instrumental color measurements, especially lightness (L*), redness (a*), and yellowness (b*) values (Apple et al., 2007). The effects of RAC and L-carnitine on

**Table 7.** Interactive effects of L-carnitine, ractopamine HCl (RAC; Elanco Animal Health, Greenfield, IN), and fat on carcass characteristics and meat quality of finishing pigs (Exp. 3)[1]

| | Fat, % | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | | 6 | | | | | | | | | | | |
| | L-carnitine, mg/kg | | | | | | | | | | | | | | | |
| | 0 | | 50 | | 0 | | 50 | | | Probability, $P <$ | | | | | | |
| | RAC, mg/kg | | | | | | | | | | | | | | | |
| Item | 0 | 10 | 0 | 10 | 0 | 10 | 0 | 10 | SED | RAC × L-carnitine × Fat | RAC × L-carnitine | L-carnitine × Fat | RAC × Fat | L-carnitine | RAC | Fat |
| Visual color | 3.39 | 3.18 | 3.48 | 3.38 | 3.38 | 3.48 | 3.45 | 3.26 | 0.09 | 0.14 | 0.62 | 0.09 | 0.44 | 0.43 | 0.26 | 0.69 |
| Firmness[2] | 2.50 | 2.96 | 2.86 | 2.98 | 2.70 | 2.76 | 2.48 | 2.64 | 0.13 | 0.26 | 0.48 | 0.04 | 0.28 | 0.83 | 0.03 | 0.05 |
| Marbling[2] | 2.44 | 2.51 | 2.45 | 2.41 | 2.46 | 2.43 | 2.18 | 2.50 | 0.15 | 0.27 | 0.60 | 0.78 | 0.53 | 0.46 | 0.47 | 0.56 |
| Lightness[3] (L*) | 45.44 | 45.73 | 45.28 | 46.14 | 45.29 | 45.81 | 46.31 | 46.45 | 0.43 | 0.42 | 0.78 | 0.27 | 0.64 | 0.10 | 0.10 | 0.32 |
| Redness[3] (a*) | 6.07 | 5.52 | 6.18 | 5.48 | 6.53 | 5.96 | 6.41 | 5.72 | 0.16 | 0.96 | 0.63 | 0.27 | 0.88 | 0.62 | 0.01 | 0.01 |
| Yellowness[3] (b*) | 0.97 | 0.95 | 0.92 | 0.83 | 1.05 | 1.12 | 1.29 | 1.28 | 0.16 | 0.87 | 0.94 | 0.29 | 0.77 | 0.48 | 0.91 | 0.03 |
| Ultimate (24-h) LM pH | 5.59 | 5.61 | 5.62 | 5.62 | 5.57 | 5.60 | 5.55 | 5.61 | 0.02 | 0.39 | 0.96 | 0.34 | 0.13 | 0.54 | 0.04 | 0.04 |
| Drip loss, % | | | | | | | | | | | | | | | | |
| Filter paper | 4.51 | 4.17 | 4.71 | 4.75 | 5.21 | 4.91 | 5.64 | 4.45 | 0.32 | 0.13 | 0.63 | 0.34 | 0.16 | 0.36 | 0.05 | 0.02 |
| Suspension | 6.92 | 6.52 | 5.81 | 6.07 | 7.29 | 6.65 | 6.98 | 6.22 | 0.41 | 0.48 | 0.56 | 0.52 | 0.27 | 0.06 | 0.22 | 0.12 |

[1]Values are means of 6 replications (pens) and 8 pigs per pen. Pigs were fed a corn-soybean meal diet with added L-carnitine (0 or 50 mg/kg) or added fat (0 or 6%) from 44.0 kg until slaughter (approximately 118 kg). Dietary RAC (0 or 10 mg/kg) was fed for the last 4 wk of the experiment.

[2]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, firmness, and marbling, respectively.

[3]Measures of dark to light (L*), redness (a*), and yellowness (b*).

instrumental color measurements of LM were inconsistent. Feeding 10 mg/kg of RAC increased L* values of LM in Exp. 2 but did not affect L* values in Exp. 3. Herr et al. (2001) and Apple et al. (2008) also observed that pigs fed 10 mg/kg RAC had greater LM L* values than pigs fed diets without RAC. In many studies, however, feeding RAC to finishing pigs did not affect pork L* values (Apple et al., 2004b; Carr et al., 2005a,b; Rincker et al., 2005). Baumgartner and Blum (1998) reported that pigs fed 25 mg/kg L-carnitine had lower LM pH at 30 min postmortem, which subsequently resulted in darker meat color. In the present study, adding L-carnitine to diets containing 5 or 10 mg/kg RAC resulted in a darker colored LM, but only in Exp. 1. Therefore, feeding RAC or L-carnitine to finishing pigs has little to no appreciable effect on the lightness or darkness of pork.

Previous research indicates that pork from pigs fed 5 or 10 mg/kg RAC is less red (lower a* values) than pork from pigs fed untreated control diets (Carr et al., 2005a,b; Rincker et al., 2005; Apple et al., 2008), which conforms with the results in 2 of the current experiments. Likewise, pork from RAC-fed pigs is often less yellow (lower b* values) than that from pigs fed control diets (Apple et al., 2004b; Carr et al., 2005a,b; Apple et al., 2008). In contrast, LM b* values did not differ between pigs fed diets with or without RAC in the current experiments.

Muscle pH affects pork color, firmness, and water-holding capacity; therefore, muscle pH at 45 min and 24 h postmortem is routinely measured (Apple et al., 2007). In the present experiments, pH measured at 45 min postmortem was unaffected by RAC or L-carnitine. On the other hand, feeding RAC at 5 mg/kg (Exp. 1) or 10 mg/kg (Exp. 2) increased ultimate (24-h) LM pH. Most studies have failed to detect an effect of 5 or 10 mg/kg RAC on either 45-min or ultimate muscle pH (Carr et al., 2005a,b; Rincker et al., 2005).

In general, feeding RAC did not affect LM temperature measured at 6 and 24 h postmortem nor did adding L-carnitine to finisher diets affect ultimate pH in 2 of the 3 experiments. Development of PSE pork is a pH- and temperature-dependent phenomenon (Sebranek and Judge, 1990) caused primarily by an accelerated rate of postmortem glycolysis that results in low muscle pH with carcass temperature remaining high, thereby causing protein denaturation (Bowker et al., 2000). However, the lack of effect of RAC or L-carnitine on pH and temperature decline indicates that feeding these carcass modifiers does not predispose pigs to PSE characteristics.

Feeding RAC did not affect drip loss in Exp. 1 and 2; however, the LM of RAC-fed in Exp. 3 had less drip loss calculated by using the filter paper method. Carr et al. (2005a) also observed a reduction in drip loss in pigs fed 10 or 20 mg/kg RAC; yet, most have reported no effect of feeding RAC on drip loss percentage (Apple et al., 2004a,b; Carr et al., 2005b; Rincker et al., 2005). In the present study, drip loss and transmission values decreased with increasing L-carnitine when fed in combination with RAC. Pigs fed L-carnitine also tended to have decreased percentage drip loss calculated using the suspension method. Supplemental dietary L-carnitine has been observed to influence the enzymes involved in lactic acid production. Owen et al. (2001) reported that pyruvate

carboxylase was increased and lactate dehydrogenase was decreased when pigs were fed added L-carnitine. An increase in pyruvate carboxylase may direct pyruvate away from lactate, which would reduce the substrate available for lactic acid synthesis postmortem. In addition, a decrease in lactate dehydrogenase may delay the onset of postmortem glycolysis. A reduction in postmortem lactic acid production would increase pH, and, therefore, could result in greater water-holding capacity and decreased percentage drip loss. However, only a numerical decrease and increase in blood lactate and pH levels, respectively, was observed in pigs fed L-carnitine.

Feeding RAC did not affect LM firmness in 2 of our 3 experiments, which is in agreement with results of other studies (Stoller et al., 2003; Carr et al., 2005a,b; Rincker et al., 2005). Similarly, adding L-carnitine to the diet did not affect muscle firmness, which is consistent with Owen et al. (2001) and Trapp et al. (2002) who failed to note an effect of added L-carnitine on pork muscle firmness.

Marbling is a quality attribute that is associated with pork palatability, and, similar to findings of others (Stoller et al., 2003; Carr et al., 2005b; Rincker et al., 2005), feeding pigs RAC did not affect LM marbling scores. In their meta-analysis, Apple et al. (2007) reported that RAC supplementation did not affect marbling scores. Furthermore, feeding L-carnitine did not affect marbling scores, which is similar to the results of Owen et al. (2001). However, Chen et al. (2008) observed an increase in marbling scores when pigs were fed diet formulated to 250 mg/kg L-carnitine suggesting that L-carnitine might also alter the lipid distribution in the muscle.

There were no interactive effects between added RAC, L-carnitine, and choice white grease on any of the pork quality measurements considered in Exp. 3. Likewise, the effects of RAC were not related to dietary fat levels. Apple et al. (2008) also observed no interactive effects on pork quality characteristics when they tested the effects of RAC and dietary fat source on the quality of LM chops during 5 d of simulated retail display. Dietary L-carnitine improved LM firmness scores only when diets were formulated without choice white grease.

In summary, feeding RAC to finishing pigs improved carcass leanness, whereas feeding L-carnitine did not affect any carcass quality measurements. Feeding RAC or L-carnitine had little to no appreciable effect on any of the pork quality measurements. However, feeding L-carnitine may reduce percentage drip loss when fed in combination with RAC.

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