Interactive effects of dietary ractopamine HCl and L-carnitine on finishing pigs: I. Growth performance[1,2]

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ABSTRACT: A total of 2,152 pigs (C22 × 336 PIC) were used in 4 experiments to determine the interactive effects of dietary L-carnitine and ractopamine HCl (RAC) on finishing pig growth performance. All trials were arranged as factorial arrangements with main effects of L-carnitine (0, 25, or 50 mg/kg in Exp. 1 and 2 and 0 or 50 mg/kg in Exp. 3 and 4) and RAC (0, 5, or 10 mg/kg in Exp. 1 and 0 or 10 mg/kg in Exp. 2, 3, and 4). Dietary carnitine was fed from 38 to 109 kg (Exp. 1 and 3) or for the last 4 or 3 wk before slaughter (118 kg; Exp. 2 and 4, respectively). Ractopamine HCl was fed for 4 wk (Exp. 1, 2, and 3) or 3 wk (Exp. 4) before slaughter. Experiments 1 and 2 were conducted in university research facilities, and Exp. 3 and 4 were conducted in a commercial research facility. All diets were formulated to contain 1.00% total Lys during the last phase of each experiment. In all experiments, pigs fed RAC had increased ($P < 0.05$) ADG and G:F compared with pigs fed no RAC. Feeding L-carnitine before the RAC feeding period did not affect pig growth performance. In Exp. 1 and 2, L-carnitine did not affect ADG during the last 4 wk; however, in Exp. 2, G:F tended (quadratic; $P = 0.07$) to improve with increasing L-carnitine. In Exp. 3, L-carnitine × RAC interactions were observed ($P < 0.04$) for ADG and G:F. Both added L-carnitine and RAC improved performance, but the response was not additive. In Exp. 4, pigs fed L-carnitine had increased ($P < 0.04$) ADG (0.88 vs. 0.84 kg) and G:F (0.36 vs. 0.35) compared with pigs fed no L-carnitine, and the response was additive to that of RAC. Analysis of treatments common to all experiments showed that pigs fed RAC had increased ($P < 0.01$) ADG (1.03 vs. 0.93 kg) and G:F (0.40 vs. 0.35) compared with pigs fed no RAC. Pigs fed L-carnitine tended to have increased ($P = 0.07$) ADG (1.00 vs. 0.96 kg) and improved ($P < 0.01$) G:F (0.38 vs. 0.37) compared with pigs not fed L-carnitine. These results confirm that RAC improves growth performance of finishing pigs. Added L-carnitine improved growth performance of finishing pigs, and the greatest response was observed in Exp. 3 and 4, which were conducted in commercial research environments. These experiments imply that adding L-carnitine to a finishing diet does not enhance the growth effects of RAC and that effects of RAC and L-carnitine on ADG and G:F are independent.

Key words: L-carnitine, pigs, ractopamine HCl

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INTRODUCTION

Ractopamine HCl (**RAC**; Elanco Animal Health, Greenfield, IN) improves growth performance and carcass leanness in pigs by repartitioning nutrients from fat deposition toward protein deposition (Apple et al., 2007). Ractopamine HCl increases protein deposition rates mainly through its effects on increased protein synthesis (Anderson et al., 1987) and decreased protein degradation (Bergen et al., 1989). However, RAC also has direct effects on fat metabolism because lipolysis is increased and lipogenesis is decreased if RAC is included in the diet (Mersmann, 2002). Increased hydrolysis of adipose tissue triglycerides leads to increased

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production of FFA, which are exported from fat cells to be used as oxidative fuels by other tissues.

Dietary supplementation of L-carnitine can increase utilization of fatty acids as energy-yielding compounds, which may lead to increased accretion of body protein (Heo et al., 2000b). The L-carnitine forms esters with long-chain activated fatty acids in the cell cytosol. This increases the capacity of the FFA to penetrate the mitochondrial membrane and utilization of fatty acids for energy production (as ATP) via β-oxidation. Owen et al. (2001a) reported that supplemental L-carnitine promoted fatty acid oxidation through accelerated β-oxidation. Adding L-carnitine to a finishing pig diet with RAC may enhance the efficiency of transport and utilization of fatty acids for energy production and further increase the growth effects attributed to RAC. Therefore, the objective of these experiments was to determine the interactive effects between RAC and L-carnitine.

MATERIALS AND METHODS

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

General

Experiments 1 and 2 were conducted at the Kansas State University Swine Teaching and Research Center, Manhattan, and Exp. 3 and 4 were conducted at a commercial research facility in southwestern Minnesota. All pigs used in these experiments were progeny of C22 sows × 336 boars (PIC USA, Hendersonville, TN). In Exp. 1 and 2, pigs were housed in an environmentally controlled building with 1.2 × 1.2 m slatted-floor pens. Each pen had a 1-hole self-feeder and a nipple waterer to allow ad libitum access to feed and water. In Exp. 3 and 4, pigs were housed in a curtain-sided building with a deep pit and completely slatted floor. The building was 12.5 × 76.2 m with 3.05 × 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 (Exp. 1, 2, and 3) or 3 wk (Exp. 4) before the end of the study. Dietary L-carnitine was fed from approximately 38 kg BW until the end of the study (Exp. 1 and 3) or for the last 4 or 3 wk before the end of the study (Exp. 2 and 4, respectively). At the end of Exp. 1, 2, and 3, pigs were slaughtered to evaluate carcass characteristics and meat quality (James et al., 2013). All dietary nutrients were formulated to meet or exceed recommended requirement estimates (NRC, 1998).

Experiment 1

Gilts (n = 126; initially, 33.4 kg) were allotted by BW and ancestry in a randomized complete block design to 1 of 9 experimental treatments arranged in a 3 × 3 factorial. There were 2 pigs per pen and 7 pens (replicates) per treatment. Pigs were fed a corn–soybean meal diet (Table 1) with added L-carnitine (0, 25, or 50 mg/kg) from 33.4 kg until the end of the experiment (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 study. Dietary RAC treatments (0, 5, or 10 mg/kg) were fed for the last 4 wk of the experiment. Weights were obtained on all pigs and feeders every 14 d during the experiment until the last 4 wk, at which time measurements were recorded weekly to calculate ADG, ADFI, and G:F.

Experiment 2

Gilts (n = 120; initially, 87.2 kg) were allotted by BW and ancestry in a randomized complete block design to 1 of 6 experimental treatments arranged in a 2 × 3 factorial. Pigs were fed a corn–soybean meal basal diet containing 1.00% Lys (16.9% CP; Table 1) with added RAC (0 or 10 mg/kg) and L-carnitine (0, 25, or 50 mg/kg) for the 4-wk experiment. There were 2 pigs per pen and 10 pens per treatment. Weights were obtained on all pigs and feeders every 7 d during the experiment to calculate ADG, ADFI, and G:F.

Experiment 3

Barrows (n = 1,104; initially, 44.0 kg) were allotted by BW in a randomized complete block design to 1 of 8 experimental treatments arranged in a 2 × 2 × 2 factorial. There were 23 pigs per pen and 6 pens per treatment. Pigs were fed a corn–soybean meal diet (Table 1) without or with added L-carnitine and without or with added fat from 44.0 kg until slaughter (approximately 118 kg). Dietary RAC treatments (0 or 10 mg/kg) were fed for the last 4 wk of the experiment. The basal diet was formulated on a total Lys:calorie basis with ratios of 3.16 g Lys/Mcal from 44.0 to 61.2 kg, 2.70 g Lys/Mcal from 61.2 to 92.0 kg, and 3.00 g Lys/Mcal from 92.0 kg until the end of the experiment. The corresponding total Lys levels 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) total Lys for the 3 phases, respectively. Weights were obtained on pens of pigs and feeders every 14 d during the experiment until the last 4 wk, at which time measurements were taken weekly to calculate ADG, ADFI, and G:F.

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

Item	Exp. 1[1] 33 kg IBW	Exp. 1[1] 74 kg IBW	Exp. 2, 87 kg IBW[2]	Exp. 3[3] 44 kg IBW No fat	Exp. 3[3] 44 kg IBW Fat	Exp. 3[3] 61 kg IBW No fat	Exp. 3[3] 61 kg IBW Fat	Exp. 3[3] 92 kg IBW No fat	Exp. 3[3] 92 kg IBW Fat	Exp. 4, 103 kg IBW[4]
Ingredient, %										
Corn	68.41	74.50	74.50	73.00	63.30	78.60	69.35	75.10	65.55	75.10
Soybean meal, 46.5% CP	26.63	22.80	22.80	24.60	28.25	19.15	22.35	22.75	26.25	22.75
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	0.64
Limestone	1.00	0.90	0.90	0.88	0.84	0.85	0.83	0.84	0.81	0.84
Salt	0.35	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	0.09
Trace mineral premix[6]	0.15	0.15	0.15	0.10	0.10	0.10	0.10	0.10	0.10	0.10
L-Lys HCl	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Tylosin premix[7]	0.05	—	—	—	—	—	—	—	—	—
DL-Met	0.01	—	—	—	—	—	—	—	—	—
Cornstarch	0.05	0.10	0.10	—	—	—	—	—	—	—
Calculated composition,[8] %										
CP (N × 6.25)	18.20	16.90	16.90	17.60	18.50	15.60	16.30	17.00	17.80	17.00
Lys	1.10	1.00	1.00	1.05	1.14	0.90	0.97	1.00	1.08	1.00
Lys:ME, g/Mcal	3.24	3.01	3.01	3.16	3.16	2.70	2.70	3.00	3.00	3.00
ME, kcal/kg	3399	3318	3318	3327	3596	3336	3605	3338	3607	3338
Ca	0.69	0.61	0.61	0.60	0.61	0.55	0.56	0.54	0.55	0.54
P	0.60	0.55	0.55	0.55	0.57	0.50	0.52	0.50	0.51	0.50

[1]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. IBW = initial BW.

[2]L-carnitine replaced cornstarch to provide 0, 25, or 50 mg/kg L-carnitine; RAC replaced cornstarch to provide 0 or 10 mg/kg RAC.

[3]L-carnitine replaced corn to provide 0 or 50 mg/kg L-carnitine; RAC replaced corn to provide 0 or 10 mg/kg RAC.

[4]L-carnitine replaced corn to provide 0 or 50 mg/kg L-carnitine; RAC 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, 6,614 IU; vitamin D_3, 992 IU; vitamin E, 26.5 IU; menadione (menadione dimethylpyrimidinol bisulfite), 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 and 4, vitamin premix provided (per kilogram of complete diet) vitamin A, 7,937 IU; vitamin D_3, 1,190 IU; vitamin E, 31.75 IU, vitamin B_{12}, 0.03 mg; riboflavin, 7.14 mg; pantothenic acid, 23.81 mg; and 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 and 4, 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 (Elanco Animal Health) per kilogram of diet.

[8]Values calculated using NRC (1998) nutrient values for the various ingredients.

Experiment 4

Barrows (n = 796; initially, 103.0 kg) were allotted by BW in a randomized complete block design to 1 of 4 experimental treatments arranged in a 2 × 2 factorial. There were 18 or 19 pigs per pen and 10 pens per treatment. The main effects were dietary L-carnitine (0 or 50 mg/kg) and RAC (0 or 10 mg/kg). Pigs were fed a corn–soybean meal diet (Table 1) without or with L-carnitine or RAC for the 3-wk experiment. The basal diet was formulated to contain 1.00% total Lys (total Lys:calorie of 3.00 g Lys/Mcal; 17.0% CP). Weights were obtained on pens of pigs and feeders weekly to calculate ADG, ADFI, and G:F.

Statistical Analyses

Data from all experiments were analyzed as a randomized complete block design using the MIXED procedure (SAS Inst. Inc., Cary, NC) with the pen as the experimental unit. Linear and quadratic polynomial contrasts were performed to determine the effects of L-carnitine level (Exp. 1) and RAC level (Exp. 1 and 2).

A secondary statistical analysis was performed to pool the growth performance data during the phase RAC was fed for all experiments. Only treatments common for all 4 experiments were combined. These included L-carnitine (0 or 50 mg/kg) and RAC (0 or 10 mg/kg). For Exp. 3, only treatments without added fat were included in the analysis. The pen was maintained as the experimental unit. The statistical model included an additional

effect of experiment and was analyzed for main effects and interactions between L-carnitine and RAC.

Least squares means were calculated for each independent variable and evaluated with the PDIFF option of SAS. Statistical significance and tendencies were set at $P \leq 0.05$ and $P < 0.10$, respectively, for all statistical tests.

RESULTS

Experiment 1

Pigs were allotted to treatments at the initiation of L-carnitine feeding and remained within the same treatment groups for the duration of the experiment. Two pens within the same treatment (50 mg/kg L-carnitine and 5 mg/kg RAC) were removed from the experiment because of clinical ileitis. During the initial period or 33 to 74 kg when graded levels of L-carnitine were fed, there were no differences in growth performance (Table 2). There were no RAC × L-carnitine interactions for ADG, ADFI, or G:F during the last 4 wk of the experiment (Table 3). Increasing RAC increased (quadratic, $P < 0.02$) ADG and G:F. Average daily gain of pigs fed 5 mg/kg RAC was similar to that of control pigs, but ADG increased and was greatest for pigs fed 10 mg/kg RAC. Gain:feed increased with increasing RAC and was greatest for pigs fed 10 mg/kg RAC. Pigs fed 25 mg/kg L-carnitine had decreased (quadratic, $P < 0.06$) ADG and ADFI compared with pigs fed 0 or 50 mg/kg L-carnitine.

Experiment 2

There were no RAC × L-carnitine interactions for ADG, ADFI, or G:F (Table 4). Feeding pigs RAC increased ($P < 0.01$) ADG and G:F. Feeding L-carnitine had no effect on ADG. However, pigs fed L-carnitine tended (quadratic, $P = 0.07$) to have increased G:F. The G:F response was due to a linear ($P < 0.01$) reduction in ADFI.

Experiment 3

There were no L-carnitine × RAC × fat interactions during the entire experiment (Table 5). There were no L-carnitine × fat interactions for growth performance of pigs between 44.0 and 92 kg (pre-RAC period). During this period, supplementing finishing pig diets with L-carnitine did not affect growth performance. As expected, the addition of 6% dietary fat increased ($P < 0.01$) ADG and G:F and decreased ($P < 0.01$) ADFI.

For the overall RAC supplementation period, there was no 3-way interaction or L-carnitine × fat interaction. However, there was an L-carnitine × RAC interaction ($P < 0.04$) for ADG and G:F. Added L-carnitine and RAC both increased ADG and G:F, but the responses were not additive. Dietary fat decreased ($P < 0.01$) ADFI and increased ($P = 0.05$) G:F during this period of growth.

Table 2. Effects of L-carnitine on growth performance of finishing pigs before ractopamine HCl was fed (Exp. 1)[1,2]

	L-carnitine, mg/kg				*P*-value		
Item	0	25	50	SED[3]	L-carnitine	Linear	Quadratic
ADG, kg	0.90	0.92	0.92	0.02	0.64	0.37	0.76
ADFI, kg	2.00	2.01	2.01	0.03	0.90	0.65	0.91
G:F	0.45	0.46	0.46	0.01	0.66	0.49	0.55

[1]$n = 126$ gilts; values are means of 21 replications (pens) and 2 pigs per pen.

[2]Values represent the period from 33.4 to 74.4 kg BW. At 74.4 kg, pigs were switched to diets containing 0, 5, or 10 mg/kg ractopamine HCl (Elanco Animal Health, Greenfield, IN) in addition to the L-carnitine levels.

[3]Standard error of the difference.

Experiment 4

There were no L-carnitine × RAC interactions for growth performance for the overall experiment (Table 6). Overall, adding RAC and L-carnitine to the diet for the last 3 wk before slaughter (118 kg) increased ADG and G:F ($P < 0.01$ and 0.04, respectively). The responses to L-carnitine and RAC were additive for ADG but not for G:F.

Overall Growth Performance

Growth performance data from common treatments of L-carnitine (0 or 50 mg/kg) and RAC (0 or 10 mg/kg) from the 4 experiments were combined (Table 7). There were no L-carnitine × RAC interactions. Feeding pigs RAC improved ($P < 0.01$) ADG and G:F in these experiments. Pigs fed L-carnitine tended to have a numerical increase in ADG ($P < 0.07$) compared with pigs fed the control diet. Pigs fed L-carnitine in the last 3 or 4 wk before slaughter also had improved ($P < 0.01$) G:F compared with pigs not fed L-carnitine. These results indicate that L-carnitine and RAC improve growth performance of finishing pigs, but the improvement was not additive.

DISCUSSION

The main effects of RAC are increased protein synthesis, but RAC also has direct effects on fat metabolism because lipolysis is increased and lipogenesis is decreased in pigs fed RAC (Mersmann, 2002). Ractopamine HCl activates β-adrenergic receptors in fat cells, causing an increase in cAMP that activates protein kinase A, which, in turn, phosphorylates hormone-sensitive lipase (Mills, 2002). Phosphorylated lipase is the activated form that initiates lipolysis. Increased hydrolysis of adipose tissue triglycerides leads to increased

Table 3. Effects of L-carnitine and ractopamine HCl (RAC) on finishing pig growth performance (Exp. 1)[1,2]

	RAC, mg/kg										*P*-value						
	0			5			10							RAC		L-Carnitine	
	L-carnitine, mg/kg										RAC ×						
Item	0	25	50	0	25	50	0	25	50	SED[3]	carnitine	RAC	Carnitine	Linear	Quadratic	Linear	Quadratic
Initial BW	72.5	74.3	74.3	74.8	75.4	75.5	75.6	74.1	74.8	1.4	0.58	0.22	0.72	0.11	0.56	0.43	0.87
ADG, kg	0.97	0.99	1.09	1.05	0.99	0.97	1.12	1.01	1.10	0.04	0.12	0.07	0.13	0.88	0.02	0.73	0.04
ADFI, kg	2.49	2.50	2.67	2.49	2.40	2.41	2.66	2.38	2.50	0.08	0.17	0.21	0.16	0.08	0.77	0.84	0.06
G:F	0.39	0.40	0.41	0.42	0.41	0.40	0.42	0.42	0.40	0.01	0.53	0.01	0.55	0.05	0.01	0.32	0.64
Final BW	98.7	101.9	104.7	104.2	103.0	102.7	107.1	102.4	105.6	2.0	0.10	0.09	0.39	0.26	0.06	0.42	0.25

[1]n = 126 gilts with an average initial BW of 74.4 kg; values are means of 7 replications (pens) and 2 pigs per pen for 28 d. The 50 mg/kg L-carnitine and 5 mg/kg RAC (Elanco Animal Health, Greenfield, IN) only had 5 replications.

[2]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.

[3]Standard error of the difference.

production of FFA, which are exported from fat cells to be used as oxidative fuels by other tissues.

Dietary supplementation of L-carnitine can increase body carnitine status and positively affect utilization of fatty acids as energy-yielding compounds, which may lead to increased accretion of body protein (Heo et al., 2000a,b). Therefore, we hypothesized that adding L-carnitine to a finishing pig diet will enhance the efficiency of transport and utilization of fatty acids for energy production and further increase the growth effects attributed to RAC. Observations in the current experiments rejected this hypothesis. Except for Exp. 3, there were no interactive effects between RAC and L-carnitine. These observations and responses in the other 3 experiments imply that adding L-carnitine to a finishing diet does not enhance the growth effects of RAC and that effects of RAC and L-carnitine on ADG and G:F are independent.

In all 4 experiments, feeding RAC consistently increased ADG and G:F of finishing pigs. Overall, finishing pigs fed diets with 10 mg/kg RAC had an 11.9% and 14.3% increase in ADG and G:F, respectively, compared with pigs fed no RAC. These observations are consistent with results of a meta-analysis of 23 published studies on RAC use in finishing pigs (Apple et al., 2007), which indicated that feeding 5, 10, or 20 mg/kg RAC increased ADG by 11% to 12% compared with untreated controls. Likewise, G:F of finishing pigs fed RAC increased by 10%, 13.3%, and 16.7% as the dosage increased from 5 to 10 to 20 mg/kg RAC, respectively. The observations herein are consistent with the results of the meta-analysis by Apple et al. (2007) and demonstrate the growth-promoting effects of RAC in finishing pigs.

The analysis of the 4 studies herein showed that supplementing finishing diets with 50 mg/kg L-carnitine increased ADG by 3% and G:F by 4%. Several studies have evaluated the effects of supplemental L-carnitine in both nursery and growing-finishing pigs, but results have been conflicting. In nursery pigs (weaning to approximately 20 kg), several studies have observed improvements in G:F (Owen et al., 1996; Cho et al., 1999; Rincker et al., 2003), likely corresponding to reduced lipid accretion (Owen et al., 1996, 2001b). However, in finishing pigs, several studies have observed no improvement in ADG or G:F with added L-carnitine (Owen et al., 2001a,b; Han and Thacker, 2006; Pietruszka et al., 2009). Only 1 study observed improved ADG and G:F (Rekiel and Zackiewicz; 2004), and a second study (Owen et al., 2001b) observed reduced carcass lipid and increased

Table 4. Effects of L-carnitine and ractopamine HCl (RAC) on growth performance of finishing pigs (d 0 to 28; Exp. 2)[1,2]

	RAC, mg/kg							*P*-value				
	0			10							Carnitine	
	L-carnitine, mg/kg							RAC ×				
Item	0	25	50	0	25	50	SED[3]	carnitine	RAC	Carnitine	Linear	Quadratic
ADG, kg	1.04	1.05	1.01	1.12	1.16	1.11	0.03	0.90	0.01	0.46	0.50	0.30
ADFI, kg	3.03	2.90	2.84	2.96	2.82	2.83	0.09	0.90	0.44	0.10	0.05	0.41
G:F	0.35	0.36	0.36	0.38	0.41	0.40	0.01	0.87	0.01	0.10	0.23	0.07

[1]n = 120 gilts with average initial BW of 87.2 kg; values are means of 10 replications (pens) and 1 or 2 pigs per pen.

[2]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; Elanco Animal Health, Greenfield, IN) for the 4-wk experiment.

[3]Standard error of the difference.

Table 5. Interactive effects of L-carnitine, ractopamine HCl (RAC), and dietary fat level on growth performance of finishing pigs (Exp. 3)[1,2]

	Fat, %															
	0				6											
	L-carnitine, mg/kg															
	0		50		0		50			*P*-value						
	RAC, mg/kg															
Item	0	10	0	10	0	10	0	10	SED[3]	RAC × carnitine × fat	RAC × carnitine	Carnitine × fat	RAC × fat	Carnitine	RAC	Fat
Pre-RAC[4]																
ADG, kg	0.94	0.91	0.93	0.94	0.98	0.99	0.99	0.99	0.02	—	—	0.97	—	0.37	—	0.01
ADFI, kg	2.52	2.46	2.47	2.51	2.46	2.40	2.44	2.42	0.03	—	—	0.97	—	0.98	—	0.01
G:F	0.37	0.37	0.38	0.38	0.40	0.41	0.40	0.41	0.01	—	—	0.73	—	0.25	—	0.01
d 0 to 28[5]																
ADG, kg	0.83	0.94	0.93	0.97	0.87	0.98	0.93	0.96	0.02	0.82	0.04	0.21	0.92	0.02	0.01	0.46
ADFI, kg	2.67	2.63	2.72	2.69	2.59	2.54	2.58	2.51	0.04	0.86	0.91	0.21	0.71	0.55	0.14	0.01
G:F	0.31	0.36	0.34	0.36	0.34	0.38	0.36	0.38	0.01	0.81	0.01	0.53	1.0	0.01	0.01	0.05

[1]*n* = 1,104 barrows; values are means of 6 replications (pens) and 22 to 26 pigs per pen.

[2]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; Elanco Animal Health, Greenfield, IN) was fed for the last 4 wk of the experiment.

[3]Standard error of the difference.

[4]Initial BW of pre-RAC period was 44.0 kg; growth performance for pre-RAC period was determined for d 0 to 51 before initiation of RAC supplementation.

[5]Average BW at initiation of RAC supplementation was 92.1 kg.

percentage lean. In the companion paper of the present paper (James et al., 2013), there were tendencies for pigs in Exp. 1, 2, and 3 to have increased percentage lean and decreased 10th rib fat depth. One proposed mechanism by which L-carnitine is hypothesized to increase protein accretion is related to downregulation of the ubiquitin proteasome system (Keller et al., 2012). The ubiquitin proteasome system regulates protein breakdown, and its downregulation would lead to greater protein accretion via reduced breakdown.

A difference between Exp. 3 and 4 and other studies is that pigs in these experiments were reared in a commercial finishing facility. Feed intake is typically less at commercial facilities than at university facilities because of environmental and space allowance differences (De La Llata et al., 2001). In our experiments, feed intake for pigs reared at the commercial research facility and not fed added fat (Exp. 3 and 4) was less (approximately 2.55 kg/d) than feed intake (approximately 2.70 kg/d) for pigs reared at the university research facility (Exp. 1 and 2), and the response to added L-carnitine was best for pigs reared at the commercial research facility (Exp. 3 and 4). Inclusion of 500 mg/kg of L-carnitine in diets fed to growing pigs (17.8 kg BW) that were restricted to 85% of voluntary feed intake reduced urinary excretion of N and improved the biological value of dietary protein 3% compared with pigs fed no L-carnitine (Heo

Table 6. Interactive effects of L-carnitine and ractopamine HCl (RAC) on commercial finishing pig growth performance (d 0 to 21; Exp. 4)[1,2]

	RAC, mg/kg							
	0		10					
	L-carnitine, mg/kg					*P*-value		
Item	0	50	0	50	SED[3]	RAC × carnitine	Carnitine	RAC
ADG, kg	0.76	0.81	0.91	0.96	0.02	0.94	0.01	0.01
ADFI, kg	2.39	2.43	2.39	2.45	0.04	0.80	0.15	0.81
G:F	0.32	0.33	0.38	0.39	0.01	0.47	0.04	0.01

[1]*n* = 740 barrows with initial BW of 103.0 kg; values are means of 10 replications (pens) and 18 or 19 pigs per pen.

[2]Pigs were fed a corn-soybean meal diet with added L-carnitine (0 or 50 mg/kg) or RAC (0 or 10 mg/kg Elanco Animal Health, Greenfield, IN) for the 3-wk experiment.

[3]Standard error of the difference.

Table 7. Meta-analysis of the interactive effects of L-carnitine and ractopamine HCl (RAC) on finishing pig growth performance (pooled data from Exp. 1, 2, 3, and 4)[1,2]

	RAC, mg/kg							
	0		10					
	L-carnitine, mg/kg					*P*-value		
Item	0	50	0	50	SED[3]	RAC × carnitine	Carnitine	RAC
ADG, kg	0.90	0.95	1.03	1.04	0.02	0.27	0.07	0.01
ADFI, kg	2.65	2.66	2.66	2.62	0.05	0.60	0.61	0.73
G:F	0.34	0.36	0.39	0.40	0.01	0.40	0.01	0.01

[1]Values are means of 33 replications from common treatments pooled across 4 different experiments. There were 2, 2, 22 to 26, and 18 to 19 pigs per pen in Exp. 1, 2, 3, and 4, respectively; initial BW of 74.4, 87.2, 92.1, and 103.0 kg for Exp. 1, 2, 3, and 4, respectively.

[2]Data from RAC (Elanco Animal Health, Greenfield, IN) feeding period (for 28 d in Exp. 1, 2, and 3 and 21 d in Exp. 4) were pooled.

[3]Standard error of the difference.

et al., 2000b). It is possible that the improved biological value of N in the L-carnitine-supplemented pigs resulted in more dietary AA being used for body protein synthesis than for energy (Heo et al., 2000b). The results by Owen et al. (2001a) support this theory. It is plausible that pigs in our experiments reared in the commercial research facility were in an energy-dependent phase of growth and not capable of maximizing protein deposition. Another difference between our experiments and those of other researchers is that previous studies have not specifically examined the last 4 wk of the finishing phase per se (Smith et al., 1996; Owen et al., 2001a,b).

These studies demonstrate that supplemental L-carnitine or RAC improve growth performance of pigs in the last 3 to 4 wk of the finishing phase; however, their effects on growth were mostly nonadditive. The response to L-carnitine was greater for pigs reared in a commercial finishing facility compared with pigs reared at a university research facility. This may be a result of the reduced feed intake observed in the commercial facility. These results should be interpreted carefully because pigs in our studies were fed Lys levels greater than those typically fed in the late finishing phase. The growth performance response of pigs to L-carnitine may be dependent on receiving a greater level of Lys that is adequate to increase protein deposition.

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