Effect of dietary L-carnitine on growth performance and body composition in nursery and growing-finishing pigs[1,2]

K. Q. Owen[3], J. L. Nelssen, R. D. Goodband[4], M. D. Tokach, and K. G. Friesen[5]

Department of Animal Sciences and Industry, Kansas State University, Manhattan 66506-0201

ABSTRACT: Two experiments were conducted to determine the effect of dietary L-carnitine on growth performance and carcass composition of nursery and growing-finishing pigs. In Exp. 1, 216 weanling pigs (initially 4.9 kg and 19 to 23 d of age) were used in a 35-d growth trial. Pigs were blocked by weight in a randomized complete block design (six pigs per pen and six pens per treatment). Four barrows and four gilts were used to determine initial carcass composition. L-Carnitine replaced ground corn in the control diets to provide 250, 500, 750, 1,000, or 1,250 ppm. On d 35, three barrows and three gilts per treatment (one pig/block) were killed to provide carcass compositions. L-Carnitine had no effect ($P > 0.10$) on growth, percentages of carcass CP and lipid, or daily protein accretion. However, daily lipid accretion tended to decrease and then return to values similar to those for control pigs (quadratic $P < 0.10$) with increasing dietary L-carnitine. In Exp. 2, 96 crossbred pigs (initially 34.0 kg BW) were used to investigate the effect of increasing dietary L-carnitine in growing-finishing pigs. Pigs (48 barrows and 48 gilts) were blocked by weight and sex in a randomized complete block design (two pigs/pen and eight pens/treatment). Dietary L-carnitine replaced cornstarch in the control diet to provide 25, 50, 75, 100, and 125 ppm in grower (34 to 56.7 kg; 1.0% lysine) and finisher (56.7 to 103 kg; 0.80% lysine) diets. At 103 kg, one pig/pen was slaughtered, and standard carcass measurements were obtained. Dietary L-carnitine did not influence growth performance ($P > 0.10$). However, increasing dietary carnitine decreased average and tenth-rib backfat (quadratic, $P < 0.10$ and 0.05), and increased percentage lean and daily CP accretion rate (quadratic, $P < 0.05$). Break point analysis projected the optimal dosage to be between 49 and 64 ppm of L-carnitine for these carcass traits. It is concluded that dietary carnitine fed during the nursery or growing-finishing phase had no effect on growth performance; however, feeding 49 to 64 ppm of L-carnitine during the growing-finishing phase increased CP accretion and decreased tenth-rib backfat.

Key Words: Pigs, Growth Performance, Carcass Characteristics, L-Carnitine

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Introduction

Carnitine is a vitamin-like compound necessary for the transport of long-chain fatty acids across the inner mitochondrial membrane, thereby facilitating β-oxidation (Fritz and Yue, 1963; Bray and Briggs, 1980). Research suggests that added dietary L-carnitine may improve the energetic efficiencies in growing salmon and swine (Ji et al, 1996; Owen et al., 1996).

Olson et al. (1989) and Baltzell et al. (1987) reported that dietary L-carnitine affects fat metabolism in human infants and suggested that carnitine is a critically important nutrient for the human neonate. Seccombe et al. (1978) observed that in newborn rats, plasma levels of carnitine increase rapidly after birth and decrease only when the pups were weaned and fed on dry diets. Because sow's colostrum and milk contain unusually high amounts of carnitine (Kerner et al., 1984), early-weaned pigs (14 to 21 d) might require added dietary L-carnitine after weaning. Owen et al. (1993, 1996) observed that feeding high levels of L-carnitine during the nursery phase improved growth performance and reduced lipid accretion rate.

Because of the reductions in lipid accretion rate in nursery pigs fed L-carnitine, growing-finishing pigs may respond similarly. Therefore, our objective was to determine the effects of increasing dietary carnitine on growth

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[3]Present address: Lonza Inc., Fair Lawn, NJ 07410.

[4]Correspondence: phone: (785) 532-1228; fax: (785) 532-7059; E-mail: Goodband@ksu.edu.

[5]Present address: Hill's Pet Nutrition, Topeka, KS 66617.

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Table 1. Percentage composition of diets (Exp. 1, as-fed basis)[a]

Item	d 0 to 14	d 14 to 35
Corn[b]	41.65	58.83
Spray-dried whey	25.00	10.00
Soybean meal, (48% CP)	14.91	21.26
Spray-dried animal plasma	7.50	—
Soybean oil	5.00	3.00
Spray-dried blood meal	1.75	2.50
Monocalcium phosphate (21% P)	1.82	1.97
Antibiotic[c]	1.00	1.00
Limestone	0.64	0.83
Vitamin and trace mineral premix[d]	0.40	0.40
DL-Methionine	0.15	0.05
L-Lysine·HCl	0.10	0.08
Copper sulfate	0.08	0.08

[a]The basal diet fed from 0 to 14 d after weaning was formulated to contain 1.50% lysine, 0.42% methionine, 0.90% Ca, and 0.80% P, and the basal diet fed from 14 to 35 d after weaning was formulated to contain 1.25% lysine, 0.35% methionine, 0.90% Ca, and 0.80% P.

[b]L-Carnitine replaced ground corn on a wt/wt basis to achieve the dietary levels of 250, 500, 750, 1,000, and 1,250 ppm carnitine.

[c]Provided 55 mg/kg carbadox.

[d]Premix provided per kilogram of complete diet: Mn, 12 mg; Fe, 165 mg; Zn, 165 mg; Cu, 16 mg; I, 0.3 mg; Se, 0.3 mg; vitamin A, 11,025 IU; vitamin D_3, 1,103 IU; vitamin E, 44 IU; menadione (menadione sodium bisulfate complex), 4.4 mg; riboflavin, 8.3 mg; D-pantothenic acid, 29 mg; niacin, 50 mg; choline, 166 mg; and vitamin B_{12}, 33 μg.

performance and tissue accretion rates in nursery and growing-finishing pigs.

Materials and Methods

General. The experimental protocols used in these studies were approved by the Kansas State University Institutional Animal Care and Use Committee. Both studies were conducted at the Kansas State University Swine Teaching and Research Center.

Experiment 1. A total of 216 weanling crossbred pigs (initially 4.9 kg and 19 to 23 d of age) was used in a 35-d study. Pigs were blocked by initial weight, equalized across treatments for ancestry and sex, and allotted to each of six dietary treatments with six pigs per pen (three barrows and three gilts) and six replicate pens per treatment. Pigs were housed in pens (1.2 m × 1.2 m) in an environmentally regulated nursery with woven wire flooring in which the initial temperature (34°C) was reduced by 1.5°C each week to maintain pig comfort. Pens contained a four-hole self-feeder and one nipple waterer to allow ad libitum access to feed and water. At weaning, pigs were assigned to one of six experimental diets: control (0) or 250, 500, 750, 1,000, or 1,250 ppm of added dietary L-carnitine. Experimental treatments were achieved by adding L-carnitine (Carniking, Lonza Inc., Fair Lawn, NJ) to the basal diet at the expense of ground corn. Experimental diets were fed in two phases: d 0 to 14 and d 14 to 35 after weaning. Pigs were fed their respective L-carnitine levels for the entire study. From d 0 to 14 after weaning, the pelleted diets (Table 1) were formulated to contain 1.50% total lysine and 0.42% methionine. From d 14 to 35 after weaning, the diets were formulated to contain 1.25% total lysine and 0.35% methionine, and were fed in meal form. Chemical composition (CP, lipid, moisture, and ash) of the diets was determined using AOAC (1995) procedures. Dietary L-carnitine was assayed by the method of Parvin and Pande (1977). Analyzed carnitine levels were 8, 245, 555, 750, 931, and 1,098 ppm in diets fed from d 0 to 14 after weaning and 5, 237, 523, 728, 841, and 1,074 ppm in diets fed from d 14 to 35 after weaning. Amino acid analysis (Knabe et al., 1989) was determined by ion exchange chromatography following acid hydrolysis of experimental diets. Analyzed amino acid concentrations were similar to calculated values (data not shown), and average lysine levels were 1.46 and 1.28% for the diets fed from d 0 to 14 and 14 to 35 after weaning, respectively. On d 14 after weaning, feeders were removed from pens, and blood samples were collected between 2 and 3 h later via vena cava puncture from four randomly selected pigs per pen. Samples were centrifuged at 2,500 × *g* for 25 min within 1 h of collection. Plasma was harvested and stored at –20°C until analysis. Samples were analyzed for plasma carnitine according to procedures described by Parvin and Pande (1977).

Pigs were weighed and feed disappearance was determined weekly to calculate ADG, ADFI, and gain:feed ratio (**G:F**). At weaning (d 0), four barrows and four gilts were selected randomly to be slaughtered for determination of initial carcass composition. After electrical stunning, the carcasses were eviscerated and heads removed. At 24 h postmortem, the carcasses were frozen, then ground once through a 15-mm plate and once through a 9-mm plate, and then homogenized for 3 min in a ribbon-paddle mixer. Subsamples were collected and analyzed to determine initial empty carcass composition (percentages of moisture, CP, lipid, and ash; AOAC, 1995). Chemical analysis (AOAC, 1995) was conducted on each sample in triplicate. On d 35, six pigs per treatment (three barrows and three gilts) were selected randomly (one from each weight block) and slaughtered to determine empty carcass composition using the same procedures. From the chemical analysis, the amounts of CP, lipid, ash, and moisture were determined for each carcass based on cold carcass weight. These components from the initial eight pigs were averaged, then subtracted from carcass chemical composition of pigs at d 35 after weaning. Tissue accretion rates were calculated as the differences between final and initial composition, divided by the days on test (35 d). The average chemical composition of the initial eight pigs was as follows: CP, 685 g (15.8%); lipid, 625 g (14.4%); moisture, 2,830 g, (67.1%); and ash, 115 g (2.7%).

Experiment 2. Ninety-six crossbred pigs (initially 34 kg BW) were used to investigate the effect of increasing dietary carnitine on growth performance and on carcass characteristics and composition. Pigs (48 barrows and 48 gilts) were blocked by weight and sex in a 2 × 6 factorial (sex × dietary carnitine) arrangement of treatments. Two pigs were housed per pen (1.5 m × 1.5 m) in

an environmentally regulated finishing barn with total slatted concrete flooring. There were eight replicate pens per treatment (four replicate pens per sex). Each pen contained a single-hole self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pig weights and feed intake were recorded every 14 d to determine ADG, ADFI, and G:F.

Basal diets were formulated for the grower (34 to 56.7 kg) and finisher (56.7 to 103 kg) phases (Table 2). All diets were corn-soybean meal based, contained 0.15% L-lysine·HCl and 2.5% soybean oil, and were fed in meal form. All other nutrients either met or exceeded NRC (1988) estimates for the 50- to 103-kg pig. Dietary L-carnitine replaced cornstarch in the basal diets (no added L-carnitine) to provide 25, 50, 75, 100, and 125 ppm. Dietary L-carnitine was assayed by the method of Parvin and Pande (1977). Analyzed dietary carnitine levels were 6, 30, 47, 77, 90, and 129 ppm for diets fed from 34 to 56.7 kg and 3, 30, 45, 77, 95, and 129 ppm for diets fed from 56.7 to 103 kg. Grower diets were formulated to contain 1.00% total lysine, and finisher diets 0.80% total lysine. Analyzed lysine levels were 1.03 and 0.82% for the grower and finisher diets, respectively.

When the mean weight of pigs in a pen reached 103 kg, one pig per pen was selected randomly and slaughtered, and standard carcass measurements were recorded. Carcasses were weighed immediately following slaughter, then chilled at 4°C for 24 h, and reweighed. At 24 h postmortem, standard carcass measurements were taken, which included average and tenth-rib backfat, longissimus muscle area, and percentages of lean and muscle. Longissimus muscle color, firmness, and marbling were evaluated according to NPPC (1991) guidelines. Percentage lean and muscle were calculated using NPPC (1991) equations with 5 and 10% fat, respectively.

Table 2. Percentage composition of diets (Exp. 2, as-fed basis)[a]

Item	Grower	Finisher
Corn	71.53	78.91
Soybean meal, (48% CP)	22.54	15.53
Soybean oil	2.50	2.50
Monocalcium phosphate, (21% P)	1.46	1.09
Limestone	0.91	0.91
Salt	0.35	0.35
Vitamin and trace mineral premix[c]	0.35	0.35
L-Lysine·HCl	0.15	0.15
Antibiotic[b]	0.10	0.10
Cornstarch[d]	0.11	0.11

[a]Grower (34 to 56.7 kg) and finisher (56.7 to 103 kg) diets were formulated to contain 1.00% and 0.80% total lysine, respectively.
[b]Provided 20 mg/kg tylosin.
[c]Premix provided per kilogram of complete diet: Mn, 12 mg; Fe, 165 mg; Zn, 165 mg; Cu, 16 mg; I, 0.3 mg; Se, 0.3 mg; vitamin A, 11,025 IU; vitamin D_3, 1,103 IU; vitamin E, 44 IU; menadione (menadione sodium bisulfate complex), 4.4 mg; riboflavin, 8.3 mg; D-pantothenic acid, 29 mg; niacin, 50 mg; choline, 166 mg; and vitamin B_{12}, 33 μg.
[d]L-Carnitine replaced corn starch in the basal diet to provide dietary carnitine levels of 25, 50, 75, 100, and 125 ppm.

The heart, liver, kidneys, and kidney fat were removed from each carcass following slaughter and weighed. A 20- to 25-g sample was taken from the same anatomical location of the heart, liver, and longissimus muscle (between the 10th and 11th rib) in each carcass for the determination of tissue carnitine concentrations using the method described by Parvin and Pande (1977). Total carnitine was analyzed on a tissue extract that was subjected to heat and alkaline pH in order to hydrolyze carnitine from acyl carnitine.

Upon initiation of the study, four barrows and four gilts were selected randomly to be slaughtered at 34 kg, for determination of initial carcass composition. After electrical stunning, the carcasses were eviscerated, and heads removed. The right side of each carcass was ground, and subsamples were used to determine initial empty body composition (percentage of moisture, CP, lipid, and ash; AOAC, 1995; table 4). The same pigs used for carcass characteristics (four barrows and four gilts per treatment) were used to determine daily accretion rates. The head, kidney fat, and viscera were removed at slaughter and were not included in the determination of tissue accretion rate. Procedures to determine carcass composition and tissue accretion rates were as described for Exp. 1. Tissue accretion rates were calculated as the difference between final (103 kg) and initial composition (34 kg), divided by the days on test (65 to 75 d). The average chemical composition of the initial eight pigs was as follows: CP, 4,190 g (19.44%); lipid, 3,732 g (17.31%); moisture, 8,336 g (60.15%); and ash, 671 g (3.1%).

Statistical Analysis. Data in Exp. 1 were analyzed as a randomized complete block design. Pigs were blocked on the basis of initial weight and equalized for sex and ancestry with pen as the experimental unit for performance data and carcass characteristics. Data in Exp. 2 were analyzed as a randomized complete block with a factorial (sex × dietary carnitine) arrangement of treatments. The pen was the experimental unit for analyses of performance data and carcass characteristics. No sex × carnitine interactions were observed ($P > 0.10$). Thus, means were pooled across gender. Analysis of variance was performed using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC), and linear and quadratic polynomials (Peterson, 1985) were evaluated for both Exp. 1 and 2. In Exp. 2, carcass data and organ weights were analyzed using cold carcass weight as a covariate. Break point analysis (Robbins, 1986) was used to determine the optimum levels of L-carnitine needed for criteria with a quadratic ($P < 0.10$) response.

Results

Experiment 1. From d 0 to 14, 14 to 35, and 0 to 35 after weaning, increasing L-carnitine had no effect ($P > 0.10$) on growth performance (Table 3). However, increasing dietary L-carnitine increased (quadratic, $P < 0.01$) plasma carnitine concentration on d 14 after weaning (Table 3). Plasma carnitine concentration increased

Table 3. Performance, body composition, and tissue accretion rates of pigs fed L-carnitine from d 0 to 35 after weaning (Exp. 1)[a]

	Added carnitine, ppm						
Item	0	250	500	750	1,000	1,250	SEM
Day 0 to 14							
ADG, g	345	340	345	349	367	363	13.3
ADFI, g	395	404	408	399	408	413	15.0
G:F	0.87	0.85	0.84	0.86	0.90	0.88	0.058
Day 14 to 35							
ADG, g	531	540	553	544	558	553	31.0
ADFI, g	971	957	1,002	970	962	1,007	59.6
G:F	0.55	0.56	0.55	0.56	0.58	0.55	0.039
Day 0 to 35							
ADG, g	454	458	472	467	481	476	25.8
ADFI, g	739	735	767	744	740	767	43.7
G:F	0.61	0.63	0.61	0.63	0.65	0.62	0.055
Plasma carnitine (d 14), nmol/mL[bc]	13.7	34.9	42.2	50.2	51.6	50.2	1.1
Carcass composition, %[d]							
Moisture	66.6	66.2	66.9	67.4	66.9	67.0	2.68
CP (N × 6.25)	17.2	17.8	16.8	17.2	16.6	17.0	1.11
Lipid	12.6	12.9	12.9	12.0	13.0	13.1	0.48
Ash	3.6	3.1	3.4	3.4	3.5	2.9	0.12
Carcass tissue accretion rates, g/d[de]							
Moisture	126	122	128	120	127	127	4.4
CP	58	56	56	53	55	56	1.9
Lipid[f]	43	42	42	37	42	45	1.1
Ash	13	10	12	11	13	10	0.4

[a]Two hundred and sixteen weanling pigs were used (initially 4.9 kg and 19 to 23 d of age) with 6 pigs per pen with 6 pens per treatment.
[b]Linear effect of dietary L-carnitine ($P < 0.01$).
[c]Quadratic effect of dietary L-carnitine ($P < 0.01$).
[d]Based on chemical analysis of 36 pigs at 35 d after weaning with one pig per pen and six replicate pens per treatment.
[e]Average of the chemical components from the initial eight pigs (four barrows and four gilts) were as follows: CP, 685 g (15.8%); lipid, 625 g (14.4%); moisture, 2,830 g (67.1%); and ash, 115 g (2.7%).
[f]Quadratic effect of dietary L-carnitine ($P < 0.10$).

up to 750 ppm and then plateaued between 750 and 1250 ppm. Percentages of carcass moisture, CP, lipid, and ash and daily accretion rates of moisture, CP, and ash were not influenced ($P > 0.10$) by dietary L-carnitine (Table 3). However, daily lipid accretion tended to be reduced (quadratic, $P < 0.10$) for pigs fed 750 ppm of L-carnitine, but then increased to values similar to those of control pigs as dietary L-carnitine increased. Break point analysis projected the optimum dosage at 762 ppm of L-carnitine.

Experiment 2. Dietary L-carnitine did not influence growth performance during the growing (34 to 56.7 kg) or finishing (56.7 to 103 kg) phases or when determined for the entire trial ($P > 0.10$; Table 4). Percentages of carcass moisture, CP, lipid, and ash and daily accretion rates of moisture, lipid, and ash were not influenced by dietary L-carnitine ($P > 0.10$; Table 4). However, daily CP accretion was increased (quadratic, $P < 0.05$) with increasing dietary L-carnitine. Break point analysis projected the optimum dosage at 64 ppm of L-carnitine. Average backfat thickness (quadratic, $P < 0.10$; Table 5) and tenth-rib backfat depth (quadratic, $P < 0.05$) were reduced by increasing dietary L-carnitine, with break point analysis projecting the optimal dosages at 59 and 56 ppm, respectively. Increasing dietary L-carnitine had no affect ($P > 0.10$) on longissimus muscle area. Dietary L-carnitine increased (quadratic, $P < 0.05$) percentages of lean and muscle, with break point analysis projecting 61 ppm, as the requirement to elicit the optimal response in both characteristics. Visual scores for longissimus color and firmness were not affected ($P > 0.20$) by dietary treatment. Visual appraisal for longissimus marbling decreased (quadratic, $P < 0.05$) as dietary L-carnitine increased (60 ppm projected as optimum by break point analysis). No effects on liver or kidney weights ($P > 0.10$) were observed. However, kidney fat weight decreased and then increased, whereas heart weights increased and then decreased (quadratic, $P < 0.01$ and $P < 0.10$, respectively) with increasing levels of dietary L-carnitine (Table 5). Tissue samples taken from the heart, liver, and longissimus muscle showed that the level of carnitine present in each tissue increased (linear, $P < 0.01$) as dietary L-carnitine increased (Table 5). Although no sex × carnitine interactions ($P > 0.10$) were observed, gilts had less tenth-rib backfat ($P < 0.05$), greater longissimus muscle area ($P < 0.01$), higher percentages of muscle ($P < 0.01$) and lean ($P < 0.01$), and better G:F ($P < 0.01$) than barrows.

Discussion

In Exp. 1, increasing dietary L-carnitine increased plasma carnitine, with concentrations appearing to

reach a plateau at 750 ppm dietary L-carnitine. This indicates that more carnitine was available for the body to use. Increases in plasma carnitine concentrations after feeding supplemental L- carnitine also has been reported by van Kempen and Odle (1995) and more recently by Heo et al. (2000).

Despite increased concentrations of carnitine in plasma, results of Exp. 1 show that increasing L-carnitine in the diet during the nursery phase had no effect on growth performance ($P > 0.10$). Owen et al. (1996), using pigs weaned at 21 d of age, found that feed efficiency from d 14 to 35 after weaning was improved by feeding up to 1,000 ppm of added L-carnitine. They also noted that the addition of 1,000 ppm L-carnitine improved ADG and ADFI from d 0 to 14 after weaning. Newton and Haydon (1988) reported that pigs fed up to 600 ppm of L-carnitine gained faster from d 0 to 14 and 0 to 20 after weaning and had greater ADFI from d 0 to 20 after weaning than those fed a control diet. Similar to our results, Hoffman et al. (1993) reported that the addition of L-carnitine to soy protein-based diets containing high levels of crude soybean oil did not improve performance of neonatal and young pigs. Differences in diet composition, especially the amount of milk products (high in carnitine), and age of pigs may be a factor in the variation in respone to added dietary L-carnitine. In addition, Newton and Burtle (1992) found high levels of dietary lysine (≥ 1.50% total lysine) to be detrimental to growth performance when supplemental L-carnitine was fed to nursery pigs (28 to 42 d of age). However, Cho et al. (1999) recently observed an improvement in nutrient digestibility and feed efficiency in nursery pigs fed added L-carnitine regardless of dietary lysine level (1.4, 1.6, or 1.8%).

Percentage carcass CP and daily protein accretion were not influenced by dietary L-carnitine. Although the percentage of carcass lipid was not affected, a trend for reduced daily fat accretion was observed with increasing dietary L-carnitine; pigs fed 750 ppm L-carnitine had the lowest numerical fat accretion rates. Similarly, Owen et al. (1993) observed a significant reduction in lipid accretion rate (26%) when 1,000 ppm L-carnitine was fed from d 0 to 35 after weaning. Also, in a second study, Owen et al. (1996) reported that pigs fed 1,000 ppm added L-carnitine from d 0 to 14 after weaning exhibited lipid accretions from d 0 to 35 after weaning that were over 20 g/d less (34% average reduction) than those of pigs fed diets without added carnitine. The magnitude of response in lipid accretion to added L-carnitine observed in the present study is much smaller than observed by Owen et al. (1996) and more recently by Heo et al. (2000) in 20-kg pigs. Furthermore, we have no explanation as to why lipid accretion values were only decreased in pigs fed 750 ppm of L-carnitine but pigs fed

Table 4. Performance, carcass composition, and tissue accretion rates of pigs fed L-carnitine from 34 to 103 kg (Exp. 2)[a]

	Added carnitine, ppm						
Item	0	25	50	75	100	125	SEM
34 to 56.7 kg							
ADG, kg	0.86	0.92	0.95	0.91	0.93	0.93	0.042
ADFI, kg	2.18	2.34	2.23	2.25	2.28	2.27	0.171
G:F	0.39	0.39	0.42	0.40	0.41	0.41	0.023
56.7 to 103 kg							
ADG, kg	0.95	0.97	0.94	0.97	0.98	0.95	0.060
ADFI, kg	3.16	3.16	3.04	3.11	3.18	3.07	0.227
G:F	0.30	0.31	0.31	0.31	0.31	0.31	0.023
34 to 103 kg							
ADG, kg	0.92	0.95	0.94	0.95	0.98	0.94	0.061
ADFI, kg	2.83	2.89	2.77	2.82	2.87	2.80	0.257
G:F	0.32	0.33	0.34	0.34	0.34	0.34	0.027
Carcass composition, %[b]							
Moisture	57.3	56.9	57.4	57.5	57.4	56.3	4.8
CP (N × 6.25)	14.3	15.2	15.8	15.3	15.3	15.5	0.78
Lipid	25.6	24.9	23.3	24.2	24.2	24.9	0.59
Ash	2.8	3.0	3.5	3.0	3.1	3.3	0.08
Accretion rates, g/d[cd]							
Moisture	416	426	420	419	421	417	21.7
CP[d]	87	101	107	102	103	102	3.5
Lipid	209	209	191	201	205	205	4.0
Ash	19	22	27	22	23	24	0.4

[a]A total of 96 pigs (48 barrows and 48 gilts) with two pigs per pen and eight replicate pens per treatment.
[b]Calculated from 48 pigs (103 kg) with one pig per pen, eight replicate pens per treatment, and four pens per sex. Hot carcass weight was used as a covariate.
[c]Average of the chemical components from the inital eight pigs were as follows: CP, 4,190 g (19.44%); lipid, 3,732 g (17.31%); moisture, 8,336 g (60.15%); and ash, 671 g (3.1%).
[d]Quadratic effect of dietary L-carnitine ($P < 0.05$).

Table 5. Carcass characteristics, organ weights, and total tissue carnitine concentrations of pigs fed L-carnitine from 34 to 103 kg (Exp. 2)[a]

	Added carnitine, ppm						
Item	0	25	50	75	100	125	SEM
Live wt, kg	102	102	103	103	102	102	23.21
Dressing percentage	74.91	75.56	74.64	74.37	74.84	75.64	15.31
Average BF,cm[b]	3.18	3.20	2.89	3.02	3.09	3.25	0.110
10th-rib BF, cm[c]	3.02	3.09	2.51	2.79	2.97	3.12	0.076
Longissimus muscle,cm^2	31.35	29.35	35.29	31.42	31.00	31.55	1.390
Percentage lean[cd]	46.04	44.86	49.54	46.91	45.91	45.61	3.111
Percentage muscle[ce]	51.56	50.83	53.95	52.26	51.51	51.20	5.431
Longissimus (10th rib)[f]							
Color	2.69	2.53	2.26	2.46	2.49	2.63	0.053
Firmness	2.94	2.67	2.68	2.90	2.76	2.81	0.090
Marbling[c]	2.81	3.02	2.50	2.41	2.81	2.94	0.066
Organ wt, g							
Liver	1,423	1,349	1,409	1,491	1,400	1,384	53.8
Heart[b]	356	348	377	373	343	344	16.2
Kidneys	356	360	347	350	355	329	9.0
Kidney fat[g]	1,368	1,215	1,120	1,181	1,345	1,440	27.5
Whole-tissue carnitine concentration, nmol/g[h]							
Muscle[i]	1,019	1,294	1,437	1,752	1,836	2,254	49.1
Liver[i]	101	127	119	154	163	195	1.7
Heart[i]	758	934	940	1,216	1,152	1,324	19.5

[a]A total of 48 pigs (24 barrows and 24 gilts) with one pig per pen and eight pigs per treatment.
[b]Quadratic effect of dietary L-carnitine ($P < 0.10$).
[c]Quadratic effect of dietary L-carnitine ($P < 0.05$).
[d]Percentage lean was calculated from NPPC (1991) equation for percentage lean with 5% fat.
[e]Percentage muscle was calculated from NPPC (1991) equation for percentage muscle with 10% fat.
[f]Loins were evaluated on a 5-point scale according to NPPC (1991) procedures.
[g]Quadratic effect of dietary L-carnitine ($P < 0.01$).
[h]Total carnitine was analyzed on a tissue extract that was subjected to heat and alkaline pH in order to hydrolyze carnitine from acyl carnitine. A total of 48 pigs (24 barrows and 24 gilts) with one pig per pen and 8 pigs per treatment.
[i]Linear effect of dietary L-carnitine ($P < 0.01$).

greater than 750 ppm had lipid accretion similar to that of controls. Because L-carnitine is water soluble and readily excreted by the kidney, it would seem unlikely that dietary concentrations greater than 750 ppm should have a detrimental effect on pig performance.

Because added L-carnitine had no effect on growth performance, we hypothesize that the early-weaned pig synthesizes enough endogenous carnitine to support normal growth. However, because increasing levels of L-carnitine tended to reduce daily lipid accretion, this suggests that providing supplemental L-carnitine affects fat metabolism. These results might be explained by findings of van Kempen and Odle (1995), using newborn pigs, which suggested that L-carnitine influences the flux rate of β-oxidation. If that is true, then fatty acid oxidation would be increased, which, in turn, would decrease daily lipid accretion rate. Results with finishing pigs shown in Exp. 2 support this concept.

In Exp. 2, tissue samples taken from the heart, liver, and muscle showed that the level of carnitine present in each tissue was increased as the level of L-carnitine increased in the diet. The liver, heart, and muscle had the lowest, intermediate, and highest tissue carnitine concentrations, respectively. These results support those of Tanphaichitr and Broquist (1974), concluding that carnitine is synthesized in the liver and stored to some degree in the heart, but primarily in the muscle.

Increasing dietary L-carnitine had no effect on growth or feed efficiency but reduced average backfat thickness, tenth-rib backfat depth; increased daily CP accretion and percentage of lean and muscle; with 49 to 64 ppm L-carnitine providing the optimum response as determined from break point analysis. The increased percentages of lean and muscle are a result of the reduced average backfat thickness and a numerical ($P > 0.10$) increase in longissimus muscle area. Also, reductions occurred in longissimus marbling and kidney fat, which suggests that dietary L-carnitine also influences internal and intramuscular fat deposition. Newton and Haydon (1989) showed that supplementing finishing diets with L-carnitine resulted in a small reduction in backfat thickness. Owen et al. (1993) demonstrated that feeding L-carnitine during the growing-finishing phase resulted in a 16% improvement in longissimus muscle area, and an 11% reduction in daily lipid accretion rate. However, L-carnitine had no effect on daily CP accretion rate, as seen in Exp. 2. Recently, Heo et al. (2000) observed that, in 20-kg pigs fed low-energy, fat-containing diets, ADG and protein accretion increased whereas lipid accretion was reduced when 500 ppm L-carnitine was added to the diet.

Carcass compositions indicate that carnitine influences not only fatty acid metabolism but also muscle metabolism. Research conducted by Ji et al. (1996), using Atlantic salmon, suggested that carnitine has other metabolic functions in addition to fatty acid transport into mitochondria. These authors presented a metabolic model in which carnitine increases pyruvate carboxylase activity and directs the flow of carbons coming from β-oxidation to glucose and amino acids, thus promoting protein synthesis. They also observed that dietary supplements of L-carnitine decreased lipid content by up to 73% and 43% and increased protein content by up to 29% and 47% in Atlantic salmon filet samples and visceral organs, respectively. Also, palmitate oxidation, lactate-dependent gluconeogenesis, and protein synthesis in hepatocytes from adult salmon were increased when L-carnitine was added to the diet. Owen (1996) observed similar results using finishing gilts fed a control diet or diets with 50 or 125 ppm added L-carnitine. Owen (1996) showed that pigs fed either amount of L-carnitine had higher rates of palmitate oxidation and increased protein synthesis in hepatocytes. Additionally, dietary L-carnitine increased the flux of pyruvate carboxylase, but decreased the flux of branched-chain keto-acid dehydrogenase in liver mitochondria and the flux of branched-chain keto-acid dehydrogenase in muscle mitochondria. These results provide evidence of carnitine's role in intermediary metabolism and provide insight into the different mechanisms involved with its utilization. However, research is needed to confirm L-carnitine's effect on intermediary metabolism in vivo.

Implications

Dietary L-carnitine had no effect on growth performance in nursery or growing-finishing pigs. However, daily lipid accretion tended to be reduced in nursery pigs. L-Carnitine increased crude protein accretion rate and percentage lean, and decreased average backfat and tenth-rib backfat thickness in growing-finishing pigs. Between 49 and 64 ppm of added L-carnitine appears to have the greatest effect on carcass traits in growing-finishing pigs. Thus, in diets for growing-finishing pigs, feeding up to 64 ppm of dietary L-carnitine may be a means to improve carcass characteristics.

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