Effects of dietary L-carnitine and dried distillers grains with solubles on growth, carcass characteristics, and loin and fat quality of growing-finishing pigs[1,2]

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ABSTRACT: A total of 1104 barrows and gilts (PIC 337 × 1050, Pig Improvement Company, Hendersonville, TN), weighing 36 ± 1 kg were used in a 109-d study to evaluate effects of dietary L-carnitine and dried distillers grains with solubles (DDGS) on growth, carcass traits, and loin and fat quality. Pigs were blocked by BW and randomly assigned to 1 of 6 treatments, with 7 pens per treatment. Treatments were arranged as a 2 × 3 factorial, with main effects of DDGS (30% in Phases 1, 2, and 3, and 20% in Phase 4) and L-carnitine (0, 50, or 100 mg/kg). Overall (d 0 to 109), dietary L-carnitine tended to improve ADG (linear, $P = 0.07$). Pigs fed 50 mg/kg L-carnitine but no DDGS had greater G:F than pigs fed 0 or 100 mg/kg, whereas when diets containing DDGS were fed, 50 mg/kg of L-carnitine reduced G:F compared with pigs fed 0 or 100 mg/kg (quadratic DDGS × L-carnitine, $P < 0.01$). There was no effect of DDGS × L-carnitine for any carcass traits, but pigs fed increasing dietary inclusion levels of L-carnitine produced heavier HCW (quadratic, $P = 0.03$), greater carcass yields (quadratic, $P = 0.07$), and greater fat depths (quadratic, $P = 0.04$), with the greatest response observed in pigs fed 50 mg/kg dietary L-carnitine. Feeding L-carnitine increased purge loss (linear, $P = 0.03$), whereas feeding DDGS tended to decrease ($P = 0.06$) LM marbling scores. The LM from pigs fed 50 mg/kg L-carnitine and DDGS had lower shear force values compared with LM chops from pigs fed either 0 or 100 mg/kg; however, shear force values were similar across dietary L-carnitine levels in diets devoid of DDGS (quadratic DDGS × L-carnitine, $P < 0.01$). Furthermore, increasing L-carnitine in DDGS diets increased fresh LM color scores, but pigs fed DDGS-free diets produced LM chops with similar subjective color scores (linear DDGS × L-carnitine, $P = 0.03$). As expected, feeding DDGS increased ($P < 0.001$) iodine value (IV) in jowl fat samples, but dietary L-carnitine did not alter IV. The concentrations of C18:2n-6 and C20:2 were decreased with increasing L-carnitine in DDGS-containing diets, but not in diets without DDGS (linear DDGS × L-carnitine, $P \leq 0.04$). Results of this study indicate that dietary DDGS did not affect growth, but led to more unsaturation of jowl fat, whereas feeding 50 mg/kg of L-carnitine improved HCW and reduced C18:2n-6 in jowl fat when fed in combination with DDGS.

Key words: carcass, dried distillers grains with solubles, fatty acid, finishing pigs, iodine value, L-carnitine

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INTRODUCTION

The primary role of carnitine in intermediary metabolism is tightly related to the β-oxidation of fatty acids (Borum, 1983). Carnitine serves an important function in transporting long-chain fatty acids into the mitochondrial matrix for subsequent β-oxidation (McGarry and Brown, 1997). Including dietary L-carnitine in swine diets has been shown to stimulate fatty acid oxidation and enhance the utilization of fat for energy (Heo et al., 2000a; Owen et al., 2001a).

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Additional research indicated that feeding dietary L-carnitine decreased lipid deposition and increased protein accretion in nursery and growing-finishing pigs (Heo et al., 2000b; Owen et al., 2001b).

Dried distillers grains with solubles (**DDGS**) are a common ingredient in swine diets; however, DDGS can have negative effects on carcass fat quality because DDGS contain 10 to 11% crude fat, which is largely composed of PUFA (Stein and Shurson, 2009). Feeding ingredients containing high concentrations of unsaturated fatty acids (**UFA**) has been shown to cause increased UFA composition and iodine value (**IV**) of pork fat (Xu et al., 2010b; Benz et al., 2011). Recently, Apple et al. (2011) reported that 100 mg/kg of L-carnitine decreased the proportion of linoleic acid in the muscle layers of fresh bellies and IV of the intermuscular fat layer in pigs fed diets containing corn oil, compared with those not fed L-carnitine, indicating that dietary L-carnitine may potentially increase carcass fat saturation in pigs fed DDGS. Therefore, the objective of this study was to investigate the effects of dietary L-carnitine and DDGS on growth performance, carcass characteristics, and fat and loin quality of finishing pigs.

MATERIALS AND METHODS

The Kansas State University Institutional Animal Care and Use Committee approved the procedures used in this study.

General

The experiment was conducted in a commercial research finishing facility in southwestern Minnesota. The building was double-curtain-sided and naturally ventilated. Each 3- by 5.5-m pen had a completely slatted flooring over a deep pit for manure storage, and was equipped with a 5-hole stainless steel, dry self-feeder and cup waterer for ad libitum access to feed and water. The building had an automated feeding system (FEEDPro, Feedlogic Corp., Willmar, MN) that delivered and measured feed on an individual pen basis.

Animals and Diets

A total of 1104 barrows and gilts [Pig Improvement Company, (**PIC**) 337 × 1050, initially 36 ± 1 kg BW] were used in a 109-d study with 26 pigs/pen and 7 pens/treatment in a completely randomized design. Pigs were housed mixed sex within pen. Pens were ranked by average pig BW, then allotted randomly to 1 of 6 dietary treatments in a 2 × 3 factorial arrangement, with 2 levels of dietary DDGS (0 vs. 30% in phases 1, 2, and 3, and 20% in phase 4) and 3 dietary levels of L-carnitine (0, 50, or 100 mg/kg). All diets were corn- and soybean-meal-based and fed in meal form, and the standardized ileal digestible (**SID**) Lys:ME was maintained at 2.84, 2.44, 2.11, and 1.81 g/Mcal for all diets in phases 1, 2, 3, and 4, respectively (Table 1). Pigs were fed a 4-phase dietary regimen, and all diets were formulated to meet or exceed all requirement estimates suggested by NRC (1998). For both DDGS and corn in diets formulation, the NRC (1998) ME value of corn (3420 kcal/kg) was used. This is due to that fact that Pedersen et al. (2007) reported that DDGS has the same energy value as corn. The DDGS nutrient composition and digestibility values used in diet formulation were determined by Stein et al. (2006) and Pedersen et al. (2007). Pigs from each pen were weighed as a group, and feed disappearance was determined every 2 wk to calculate ADG, ADFI, and G:F.

Loin and Jowl Fat Collection and Analysis

On d 83 of the experiment, the 3 visually-appraised heaviest pigs were removed from each pen and sold in accordance with the normal marketing procedure of the farm. These pigs were not included in carcass data analysis, but were included in the growth portion of the trial. On d 97 of the experiment, 1 barrow and 1 gilt were randomly selected from each pen, tattooed according to gender and pen number, and transported approximately 1 h to a commercial packing plant (Sioux-Preme Packing Co., Sioux Center, IA) for collection of jowl fat and whole loins (Institutional Meat Purchase Specifications 413).

After slaughter, the whole boneless loins and approximately 250 g of jowl were collected from the right side of each carcass. Loins were individually vacuum-packaged, and each jowl sample was packaged in a sealable plastic bag. After packaging, all loins and jowl samples were stored in a cooler containing ice and transported approximately 5 h to the Kansas State University Meat laboratory, where samples were stored at 0 to 4°C until analyses were conducted.

Approximately 11 d postmortem, LM quality was evaluated by trained, experienced university personnel. Purge loss was measured by weighing the whole loin in the packaging bag, removing the loin and blotting it dry, and reweighing the loin and dried packaging bag. Percentage purge loss was calculated as 100 × (initial loin weight – packaging bag weight – final loin weight)/(initial loin weight – packaging bag weight). After measuring purge loss, several 2.54-cm-thick, center-cut LM chops were cut from each loin and were allowed to bloom 1 h before taking the subjective and instrumental color measurements. Instrumental LM color (CIE L*, a*, and b* values) was measured (MiniScan XE Plus Spectrophotometer, Model 45/0 LAV; Hunter Associate Laboratory, Inc., Reston, VA), with a 2.54-cm-diameter

Table 1. Diet composition (as-fed basis)[1]

	Phase 1		Phase 2		Phase 3		Phase 4	
Item	0 % DDGS	30% DDGS	0% DDGS	30% DDGS	0% DDGS	30% DDGS	0% DDGS	20% DDGS
Ingredient, %								
Corn	76.65	52.30	80.95	56.55	84.60	60.15	85.75	69.50
Soybean meal (46.5% CP)	20.85	15.45	16.75	11.25	13.30	7.80	12.40	8.75
DDGS	–	30.00	–	30.00	–	30.00	–	20.00
Monocalcium P (21% P)	0.55	–	0.40	–	0.33	–	0.25	–
Limestone	0.95	1.25	0.98	1.23	0.95	1.15	0.93	1.08
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin and trace mineral premix[2]	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09
L-Thr	0.06		0.04	–	0.03	–	–	–
L-Lys[3]	0.45	0.55	0.40	0.50	0.35	0.46	0.20	0.27
Phytase[4]	0.01	0.005	0.01	0.003	0.01	0.002	0.01	0.0045
L-carnitine[5]	–	–	–	–	–	–	–	–
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis								
SID AA, %								
Lys	0.95	0.95	0.82	0.82	0.71	0.71	0.61	0.61
Ile:Lys	62	69	64	71	65	74	73	80
Met:lys	28	33	29	36	30	39	34	41
Met & Cys:Lys	56	67	59	73	61	80	70	84
Thr:Lys	61	63	61	66	63	70	66	75
Trp:Lys	17.0	17.0	17.0	17.0	17.0	17.0	19.0	19.0
Total Lys, %	1.06	1.11	0.92	0.97	0.80	0.86	0.70	0.73
ME, Mcal/kg	3.35	3.36	3.35	3.36	3.36	3.36	3.36	3.36
SID Lys:ME, g/Mcal	2.84	2.83	2.44	2.44	2.11	2.11	1.81	1.81
CP, %	16.6	20.2	15.0	18.6	13.7	17.2	13.2	15.6
Ca, %	0.56	0.56	0.53	0.53	0.49	0.49	0.47	0.47
P, %	0.47	0.47	0.43	0.45	0.40	0.44	0.38	0.40
Available P, %	0.28	0.28	0.25	0.25	0.23	0.23	0.21	0.21

[1]DDGS = dried distillers grains with solubles; and SID = standardized ileal diegestible. Phase 1 diets were fed from 36 to 61 kg. Phase 2 diets were fed from 61 to 84 kg. Phase 3 diets were fed from 84 to 109 kg. Phase 4 diets were fed from 109 to 127 kg. Grower phase was from 36 to 84 kg BW, and finisher phase was from 61 to 109 kg BW.

[2]Provided per kilogram of premix: 4509,409 IU vitamin A; 701,464 IU vitamin D_3; 24,050 IU vitamin E; 1402 mg vitamin K; 12,025 pantothenic acid; 18,037 mg niacin; 3006 mg vitamin B_2 and 15,031 mg vitamin B_{12}, 40,084 mg Mn from manganese oxide, 90,188 mg Fe from iron sulfate, 100,209 Zn from zinc oxide, 10,021 mg Cu from copper sulfate, 501 mg I from ethylenediamin dihydroiodide, and 300 mg Se from sodium selenite.

[3]Biolys (Evonik Degussa Corp., Kennesaw, GA) contains 50.7% L-Lys.

[4]OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 0.12% available P.

[5]Carniking 10 (Lonza, Inc., Allendale, NJ) replaced corn to provide 0, 50, or 100 mg/kg L-carnitine.

aperture, 10° standard observer, and illuminant D65 using the average of 3 readings. Visual color and marbling were evaluated using the NPPC (2000) color and marbling standards. Loin pH was taken on a cross-section of the LM located at the center region immediately posterior to the *spinalis dorsi* muscle using a pH meter (Model HI9025; HANNA Instruments, Woonsocket, RI).

One chop from each loin was weighed, placed in a plastic bag, and sealed immediately after fabrication. After storage at 0 to 4°C for 24 h, each chop was removed from the bag, blotted dry with paper towels, and reweighed to measure percentage drip loss.

Chops for Warner-Bratzler Shear Force (**WBSF**) were vacuum packaged and subsequently frozen at –40°C. Chops were thawed at 0 to 4°C for approximately 24 h, then cooked in an oven (Model DFC-102; The G.S. Blodgett Co., Burlington, VT) preheated to 163°C. When chops reached 40°C, they were turned and cooked to a final internal temperature of 70°C. Chop temperatures were monitored with thermocouple wires (30-gauge copper and constantan; Omega Engineering, Stamford, CT) inserted into the approximate geometric center of each chop and attached to a Doric temperature recorder (Model 205; Vas Engineering, San Francisco, CA). Chops were then covered with plastic wrap and refrigerated at 3 to 4°C for 24 h. Six 1.27-cm diameter cores were obtained from each chop parallel to the long axis of the muscle fibers. Each core was sheared once perpendicular to the direction of the muscle fibers using a Warner-Bratzler V-shaped blunt blade (G-R Manufacturing Co., Manhattan, KS) attached to a testing machine (Instron Universal Testing Machine,

Model 4201, Instron Corp., Canton, MA) with a 50-kg compression load cell and a crosshead speed of 250 mm/min. Peak shear force values were recorded, and values of the 6 cores were averaged for statistical analysis.

Jowl fat samples were thawed and dissected to separate adipose tissue from skin and lean tissue. All fat tissues were cut and then frozen in a bath of liquid N_2, then ground into fine particles by a blender (Dynamics Corp. of America, New Hartford, CT). Approximately 50 μg of ground fat were weighed into a tube and mixed with 3 mL of methanolic-HCl and 2 mL of internal standard [2 mg/mL of methyl heptadecanoic acid (C17:0) in benzene] and then heated in a water bath for 120 min at 70°C for transmethylation. After cooling, 2 mL of benzene and 3 mL of K_2CO_3 were added to extract and transfer methyl esters into a vial for subsequent quantification of the methylated fatty acids by gas chromatography. Injection port and detector temperatures were 250°C with a flow rate of 1 mL/min helium and a split ratio of 100:1. Oven temperature began at 140°C, increased at 2°C/min to 200°C, increased at 4°C/min to 245°C, and was held for 17 min.

From the fatty acid analysis, IV was calculated from this equation (AOCS, 1998): IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723. The fatty acid results are represented as a percentage of the total fatty acids in the sample.

Carcass Characteristics

At the end of the 109-d experiment, the remainder of pigs were individually tattooed according to pen number to allow for carcass data collection at the packing plant and data retrieval by pen. Pigs were transported approximately 96 km to a packing plant (JBS Swift and Co., Worthington, MN) for processing and collection of HCW, backfat thickness, and loin depth. Dressing percentage was calculated by dividing the HCW by the BW obtained at the packing plant before slaughter. These carcass measurements were collected with pen as the experimental unit.

Statistical Analysis

Analysis of variance was performed using the mixed models procedure (SAS Inst. Inc., Cary, NC). All data were analyzed as a completely randomized design with pen as the experimental unit. The statistical model included the fixed effect of dietary treatment and the interaction between DDGS and L-carnitine dosage was evaluated using linear or quadratic DDGS × L-carnitine preplanned contrasts. Also, the main effects of DDGS, and linear or quadratic effects of L-carnitine dosage were evaluated using contrasts. Backfat, loin depth, and percentage lean were adjusted to a common HCW as a covariate. Individual carcass observations were adjusted by using pen and gender as a random effect in the statistical model. Results are reported as LS MEANS and were considered significant at $P \leq 0.05$ and a trend at P values between 0.05 and 0.10.

RESULTS

Growth and Carcass

From d 0 to 55, ADG (linear, $P = 0.06$) and ADFI (quadratic, $P = 0.05$) increased as dietary L-carnitine increased in the diet (Table 2). Including DDGS in diets reduced ($P = 0.03$) G:F during the first 55 d on trial, but G:F was increased by L-carnitine only when fed in diets containing 30% DDGS (linear DDGS × L-carnitine, $P = 0.05$). Additionally, ADFI increased (quadratic, $P < 0.05$) in pigs fed increasing amounts of L-carnitine. Pigs fed DDGS had poorer ($P < 0.03$) G:F than those fed no DDGS.

During the last 44 d of the feeding trial, ADG tended to increase quadratically ($P = 0.09$) with increasing dietary L-carnitine levels, with the greatest response observed at 50 mg/kg (Table 2). Daily feed intake was not affected by any dietary treatments between d 55 and 109; however, G:F increased in response to L-carnitine level in diets formulated without DDGS, but decreased with increasing L-carnitine when fed in combination with DDGS (quadratic DDGS × L-carnitine, $P = 0.01$).

Overall, there was a trend for improvements in ADG across the 109-d feeding period as L-carnitine was increased in the diet (linear, $P = 0.07$; quadratic, $P = 0.07$). Even though ADFI was similar across all treatments, dietary inclusion of L-carnitine caused a quadratic increase in G:F when DDGS-free diets were fed but a quadratic decrease when included in DDGS diets (quadratic DDGS × L-carnitine, $P = 0.01$).

There were no DDGS × L-carnitine interactions for any carcass composition measures, and formulating diets with DDGS did not alter slaughter weight, HCW, dressing percentage, or fat depth (Table 3). Hot carcass weight ($P = 0.03$), dressing percentage ($P = 0.07$), and fat depth ($P = 0.04$) increased quadratically with increasing L-carnitine levels in the diet, with the greatest responses observed in pigs fed 50 mg/kg of L-carnitine. Also, increasing the dietary level of L-carnitine increased backfat (quadratic, $P < 0.04$) and tended to increase carcass yield (quadratic, $P < 0.07$), with the greatest response observed in pigs fed 50 mg/kg dietary L-carnitine. Additionally, LM depth tended to be reduced ($P = 0.09$) in pigs fed DDGS.

Loin Quality

Neither LM pH nor drip loss was affected by any dietary treatment; however, loin purge loss increased with increasing dietary L-carnitine levels (linear, $P < 0.03$), and feeding DDGS tended to reduce ($P = 0.06$) LM marbling

Table 2. Effect of dietary L-carnitine (mg/kg) and dried distillers grains with solubles (DDGS) on growth performance[1]

	No DDGS with L-carnitine			DDGS with L-carnitine				*P*-value				
								DDGS × L-carnitine			L-carnitine	
Item	0	50	100	0	50	100	SEM	Linear	Quadratic	DDGS	Linear	Quadratic
d 0 to 55												
ADG, kg	0.86	0.89	0.89	0.85	0.88	0.87	0.01	0.70	0.64	0.16	0.06	0.20
ADFI, kg	2.16	2.21	2.22	2.20	2.29	2.15	0.04	0.10	0.14	0.58	0.84	0.05
G:F	0.400	0.401	0.400	0.386	0.384	0.405	0.005	0.05	0.13	0.03	0.05	0.22
d 55 to 109												
ADG, kg	0.76	0.82	0.79	0.80	0.81	0.81	0.02	0.48	0.12	0.12	0.23	0.09
ADFI, kg	2.67	2.67	2.74	2.76	2.84	2.70	0.05	0.23	0.12	0.12	0.90	0.40
G:F	0.285	0.306	0.288	0.291	0.285	0.301	0.006	0.64	0.01	0.88	0.32	0.45
d 0 to 109												
ADG, kg	0.81	0.85	0.84	0.83	0.85	0.84	0.01	0.50	0.46	0.83	0.07	0.07
ADFI, kg	2.40	2.42	2.47	2.46	2.55	2.41	0.04	0.12	0.10	0.20	0.86	0.15
G:F	0.340	0.352	0.342	0.336	0.332	0.350	0.005	0.24	0.01	0.18	0.14	0.99
Final BW, kg	121.9	125.8	124.8	123.5	125.2	125.1	1.2	0.62	0.46	0.68	0.07	0.12

[1]A total of 1104 barrows and gilts (Pig Improvement Company, PIC 337 × 1050, initial BW 36 ± 1 kg) were used in a 109-d experiment with 27 pigs per pen and 7 pens per treatment.

scores (Table 4). Visual color scores of the LM increased with increasing dietary L-carnitine levels when pigs were fed DDGS, but LM color scores were similar across L-carnitine inclusion levels when pigs consumed DDGS-free diets (linear DDGS × L-carnitine, $P = 0.03$). Even though L* and a* values were similar across the dietary treatments, the LM from pigs fed 50 mg/kg was the most yellow (greatest b* value) when DDGS were not included in the diet, but the least yellow (lowest b* value) when pigs consumed DDGS diets (quadratic DDGS × L-carnitine, $P = 0.09$). When DDGS was formulated in the diets, loins from pigs fed 50 mg/kg of L-carnitine had lower WBSF values than those from pigs fed either 0 or 100 mg/kg of L-carnitine; however, WBSF values were similar across the dietary L-carnitine inclusion levels in diets devoid of DDGS (quadratic DDGS × L-carnitine, $P < 0.01$).

Jowl Fat Composition

The jowl fat from pigs consuming DDGS diets had lower ($P \leq 0.07$) percentages of all SFA, as well as percentages of myristic (14:0), plamitic (16:0), and stearic (18:0) acids, than jowl fat from pigs fed DDGS-free diets (Table 5). In addition, DDGS reduced ($P < 0.001$) the proportions of palmitoleic (16:1), oleic (18:1cis-9), vaccenic (18:1n-7), and all MUFA in the jowl fat samples when compared with samples from pigs fed diets devoid of DDGS. On the other hand, including DDGS in swine diets increased the total PUFA composition ($P < 0.001$) of the jowl fat, as well as the total trans fatty acids (**TFA**, $P = 0.02$), UFA:SFA and PUFA:SFA ($P < 0.001$), and the IV ($P < 0.001$) of the jowl fat. Dietary L-carnitine failed to affect the weight percentages of 14:0, 16:0, 16:1, 18:0, 18:1cis-9, 18:1n-7, α-linolenic acid (18:3n-3), arachidonic acid (20:4n-6), total SFA, total MUFA, and total PUFA, as well as the UFA:SFA, PUFA:SFA, and IV of jowl fat. The proportions of margaric acid (17:0) and TFA increased in response to dietary inclusion of L-carnitine (linear, $P \leq 0.02$). The proportions of lineoleic (18:2n-6) and eicosadienoic (20:2) acids increased with increasing dietary L-carnitine when DDGS-free diets were fed, but the proportions of these 2 fatty acids decreased with

Table 3. Effect of dietary L-carnitine (mg/kg) and dried distillers grains with solubles (DDGS) on carcass traits[1]

	No DDGS with L-carnitine			DDGS with L-carnitine				*P*-value				
								DDGS × L-carnitine			L-carnitine	
Item	0	50	100	0	50	100	SEM	Linear	Quadratic	DDGS	Linear	Quadratic
BW,[2] kg	123.8	125.7	124.4	123.5	125.3	125.2	1.2	0.63	0.75	0.95	0.35	0.23
HCW, kg	92.4	95.4	93.2	92.6	94.2	94.1	0.9	0.70	0.28	0.95	0.17	0.03
Yield,[3] %	74.7	75.9	75.0	75.0	75.2	75.1	0.3	0.84	0.17	0.80	0.52	0.07
Backfat,[4] cm	1.67	1.75	1.72	1.65	1.72	1.65	0.03	0.44	0.87	0.14	0.56	0.04
Loin depth,[4] cm	6.36	6.39	6.34	6.23	6.21	6.23	0.11	0.94	0.74	0.09	0.92	0.91
Lean,[4] %	56.3	55.9	56.0	56.3	55.9	56.3	0.2	0.48	0.79	0.76	0.56	0.11

[1]A total of 775 pigs were used for obtaining carcass data with 7 pens per treatment.

[2]Body weight was obtained at packing plant.

[3]Percentage yield was calculated by dividing HCW by BW obtained at the packing plant.

[4]Values were adjusted to a common carcass weight by using carcass weight as a covariate in the model.

Table 4. Effect of dietary L-carnitine (mg/kg) and dried distillers grains with solubles (DDGS) on loin quality[1]

	No DDGS with L-carnitine			DDGS with L-carnitine				*P*-value				
								DDGS × L-carnitine			L-carnitine	
Item	0	50	100	0	50	100	SEM	Linear	Quadratic	DDGS	Linear	Quadratic
Purge loss, %	2.71	3.38	3.47	2.46	2.92	3.45	0.38	0.76	0.63	0.45	0.03	0.70
Drip loss, %	1.08	1.24	1.36	1.33	0.95	1.35	0.16	0.41	0.14	0.90	0.34	0.17
Shear force,[2] kg	3.16	3.33	3.34	3.55	2.90	3.52	0.17	0.53	0.01	0.74	0.64	0.05
pH	5.57	5.57	5.53	5.58	5.59	5.57	0.02	0.57	0.82	0.17	0.25	0.43
Color score[3]	3.5	3.5	3.3	3.1	3.4	3.5	0.1	0.03	0.94	0.54	0.29	0.34
Marbling score[4]	1.9	2.1	1.8	1.7	1.8	1.6	0.2	0.91	0.73	0.06	0.65	0.27
Lightness (L*)[5]	53.6	55.1	54.3	54.5	55.3	55.2	0.7	0.97	0.51	0.21	0.28	0.14
Redness (a*)[6]	8.4	8.1	7.4	7.9	7.4	8.1	0.4	0.12	0.23	0.55	0.32	0.63
Yellowness (b*)[7]	15.5	15.9	14.9	15.7	15.4	15.8	0.3	0.31	0.09	0.51	0.38	0.49

[1]Values represent the mean of 84 observations (12 replications per treatment) and were adjusted by using gender as a covariate in the model.

[2]Warner-Bratzler Shear Force.

[3]1 = pale pinkish gray to white, 2 = grayish pink, 3 = reddish pink, 4 = dark reddish pink, 5 = purplish red, and 6 = dark purplish red (NPPC, 2000).

[4]1.0 = 1% intramuscular fat and 10 = 10% intramuscular fat (NPPC, 2000).

[5]L* = measure of darkness to lightness (greater L* value indicates a lighter color).

[6]a* = measure of redness (greater a* value indicates a redder color).

[7]b* = measure of yellowness (greater b* value indicates more yellow color).

increasing dietary L-carnitine when fed in combination with DDGS (linear DDGS × L-carnitine, $P \leq 0.04$).

DISCUSSION

Growth Performance

Researchers have reported that endogenous carnitine is synthesized in sufficient quantity to support growth performance of finishing pigs (Rebouche and Seim, 1998); however, results of the current experiment demonstrated improvements in ADG with the addition of L-carnitine in both the growing and finishing periods, which also resulted in an overall effect. James et al. (2002c,d) observed that pigs reared in a commercial facility and fed diets containing 50 mg/kg L-carnitine during the last 3 to 4 wk before slaughter had improved growth performance, which was in contrast to a number of studies where L-carnitine did not affect ADG of growing-finishing pigs (Smith et al., 1996; Owen et al., 2001a,b). The differing responses may be attributed to the environment in which the research was conducted. Most of the previous studies were conducted in controlled, university facilities, whereas the current study and that of James et al. (2002c,d) were conducted in commercial facilities. Because of some environmental factors (i.e., stocking density, health status, and temperature regulation), pigs reared in commercial facilities typically have lower feed intake than pigs reared in university facilities (De la Llata et al., 2001). Reduced feed intake causes less energy intake, which can result in pigs failing to meet the energy requirement for maximum growth. Reductions in ADFI cause restrictions in energy intake, and Heo et al. (2000b) suggested that supplemental L-carnitine increased β-oxidation of fatty acids and maintained protein synthesis of growing pigs limited in DE intake.

Similar to the results of the present study, James et al. (2002c) reported that including 50 mg/kg of L-carnitine in corn-soybean meal-based finisher diets improved G:F. However, adding 50 mg/kg of L-carnitine to DDGS-based diets actually reduced G:F, and the exact mechanism(s) for this reduction in growth efficiency is largely unknown at this time.

The L-carnitine also has been evaluated in diets during the nursery phase when feed intake can limit maximum growth performance, which is consistent with other research. Rincker et al. (2003) conducted 5 experiments and found that most of the benefits of dietary L-carnitine in growth performance of nursery pigs were observed during the period from 2 to 5 wk after weaning when no added animal protein sources were included in the diet. Also, Owen et al. (1996) found nursery pigs fed L-carnitine had improved G:F when fed diets containing 1000 mg/kg L-Canitine for 14 d postweaning, but ADG was not influenced. This result could be due to insufficient synthesis of endogenous carnitine (Borum, 1983), which resulted in supplemental carnitine improving growth of young pigs. Therefore, L-carnitine supplementation may aid in supplying available energy when insufficient endogenous carnitine is produced or energy intake is not sufficient to meet normal growth.

In the current study, dietary DDGS did not affect overall growth performance. Diet formulation with 30%, or less, of DDGS did not affect growth performance of finishing pigs (Stein and Shurson, 2009). More recently, Cromwell et al. (2011) observed that 45% dietary DDGS did not affect growth performance of growing-finishing

Table 5. Effect of dietary L-carnitine (mg/kg) and dried distillers grains with solubles (DDGS) on jowl fatty acid profile[1]

	No DDGS with L-carnitine			DDGS with L-carnitine				*P*-value				
								DDGS × L-carnitine			L-carnitine	
Item	0	50	100	0	50	100	SEM	Linear	Quadratic	DDGS	Linear	Quadratic
Fatty acid, % of total fatty acids												
Myristic acid (14:0)	1.45	1.44	1.40	1.35	1.40	1.35	0.03	0.38	0.46	0.007	0.46	0.15
Palmitic acid (16:0)	22.70	22.56	22.21	20.65	21.23	20.95	0.22	0.07	0.39	0.001	0.66	0.15
Palmitoleic acid (16:1)	3.29	3.36	3.10	2.76	2.80	2.81	0.15	0.41	0.55	0.001	0.64	0.49
Margaric acid (17:0)	0.45	0.40	0.51	0.48	0.46	0.48	0.02	0.24	0.19	0.28	0.16	0.02
Stearic acid (18:0)	9.35	9.30	9.39	8.33	8.55	8.71	0.23	0.45	0.79	0.001	0.34	0.91
Oleic acid (18:1 cis-9)	40.99	41.30	41.24	38.13	38.44	37.81	0.42	0.49	0.69	0.001	0.93	0.36
Vaccenic acid (18:1n-7)	4.65	4.78	4.65	4.13	4.17	4.18	0.13	0.86	0.59	0.001	0.84	0.51
Linoleic acid (18:2n-6)	12.57	13.97	14.41	18.58	16.34	16.62	0.83	0.03	0.24	0.001	0.95	0.59
α-Linoleic acid (18:3n-3)	0.51	0.51	0.51	0.64	0.61	0.65	0.02	0.96	0.28	0.001	0.74	0.17
Arachidic acid (20:0)	0.20	0.21	0.22	0.19	0.19	0.22	0.01	0.84	0.55	0.42	0.07	0.59
Eicosadienoic acid (20:2)	0.67	0.67	0.72	0.95	0.91	0.89	0.03	0.04	0.74	0.001	0.68	0.52
Arachidonic acid (20:4n-6)	0.10	0.09	0.10	0.11	0.10	0.10	0.00	0.09	0.85	0.001	0.37	0.12
Total SFA,[2] %	35.12	34.77	34.75	32.07	32.73	32.71	0.35	0.14	0.40	0.001	0.69	0.77
Total MUFA,[3] %	49.88	50.33	49.98	45.93	46.31	45.66	0.53	0.72	0.90	0.001	0.87	0.31
Total PUFA,[4] %	13.73	13.72	13.92	20.61	19.67	20.24	0.55	0.60	0.48	0.001	0.87	0.35
Total TFA[5] %	0.34	0.32	0.36	0.39	0.34	0.40	0.02	0.69	0.28	0.02	0.45	0.01
UFA:SFA[6]	1.82	1.85	1.84	2.08	2.02	2.02	0.03	0.13	0.37	0.001	0.52	0.87
PUFA:SFA[7]	0.39	0.40	0.40	0.65	0.60	0.62	0.02	0.35	0.39	0.001	0.62	0.38
Iodine value,[8] g/100g	66.50	66.85	66.89	74.66	73.33	73.95	0.64	0.38	0.29	0.001	0.80	0.44

[1]Values represent the mean of 84 observations (12 replications per treatment).

[2]Total SFA = [C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0], where the brackets indicate concentration.

[3]Total MUFA = [14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1], where the brackets indicate concentration.

[4]Total PUFA = [C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n6], where the brackets indicate concentration.

[5]Total trans fatty acids (TFA) = [C18:1t] + [C18:2t] + [C18:3t], where the brackets indicate concentration.

[6]Unsaturate fatty acid (UFA):SFA = [total MUFA + total PUFA]/total SFA.

[7]PUFA:SFA = total PUFA/total SFA.

[8]Iodine value = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723, where the brackets indicate concentration.

pigs, but Whitney et al. (2006) reported ADG and G:F were decreased when pigs were fed up to 30% DDGS during the finishing period. The difference between the Whitney et al. (2006) and the present study may be attributed to the fact that diets in the present study were formulated on a digestible Lys basis, whereas the Whitney et al. (2006) diets were on a total Lys basis.

Carcass Characteristics

Past research indicated that feeding supplemental L-carnitine reduced backfat and increased lean percentage of finishing pigs (Owen et al., 2001a, 2001b). Carnitine palmitoyltransferase-I is considered a key enzyme in regulating fatty acid oxidation (McGarry and Brown, 1997), which may cause a reduction in backfat development in finshing pigs. Heo et al. (2000a) reported that dietary L-carnitine increased the activity of carnitine palmitoyltransferase-I in muscle and liver of growing pigs, but a number of experiments reported no effect of dietary L-carnitine on backfat and loin depths (James et al., 2002c,d; Bertol et al., 2005). This inconsistency may be due to the difference in final BW of pigs. The final BW (>110 kg) of pigs used in this study was greater than that (103 kg) of the pigs used in the Owen et al. (2001a,b) studies. Heavier pigs in the current study may have greater lipid accretion rate and decreased lean tissue deposition. In addition, Owen et al. (2001a) observed that dietary L-carnitine resulted in greater rates of palmitate oxidation, more rapid flux through pyruvate carboxylase, and reduced flux through branched-chain α-keto acid dehydrogenase, which indicated that more fat was metabolized and used for energy. Heo et al. (2000b) suggested that 500 mg/kg L-carnitine supplementation improved protein synthesis when limited in ME intake, but lipid accretion of growing pigs was not affected. Owen et al. (1996) reported that nursery pigs fed 1000 mg/kg L-carnitine for 14 d postweaning had less carcass lipid accretion on d 35 postweaning (d 35 BW = 20 kg).

Dietary DDGS did not influence carcass traits in this study. Stein and Shurson (2009) summarized that dietary corn DDGS had no effects in most past research on carcass measurements, including HCW, backfat, loin

depth, and carcass lean percentage. In some studies, it was observed that pigs fed DDGS diets had reduced dressing percentage (Whitney et al., 2006; Xu et al., 2010b); however, dietary corn DDGS had no effect on dressing percentage in other experiments (Xu et al., 2010a; Cromwell et al., 2011) or in the present study. This result might be explained by other research demonstrating that reducing or withdrawing DDGS from pig diets for a period of time before marketing mitigated the decrease in dressing percentage compared with pigs fed a constant level until marketing (Jacela et al., 2009).

Loin Characteristics

The results of the current study showed that dietary L-carnitine increased purge loss of LM, which means less water-holding capacity and possible negative effects on sensory traits including juiciness, flavor, and tenderness (Huff-Lonergan and Lonergan, 2005). Purge loss is a concern of packers because product yield at the plant may be reduced before carcass or product shipping from the processing plant. Present results demonstrated that dietary L-carnitine increased LM purge losses, which negatively affect packers and retailers by reducing the quantity of saleable product because of water loss in the packaging itself. Conversely, another indicator of LM water-holding capacity, drip loss percentage, was not affected by feeding dietary L-carnitine in the present study. James et al. (2002b) reported that dietary L-carnitine supplementation decreased drip loss when measured 24-h postmortem. Moreover, James et al. (2002b) observed an increase in LM pH by feeding carnitine, but LM pH did not differ among treatments in the current study. Thus, the increase in loin purge losses observed in the present study may be attributed to the heavier HCW of pigs fed L-carnitine, because heavier carcasses chill more slowly because of greater overall mass.

The present results indicated that L-carnitine supplementation did not influence color and marbling scores, which are consistent with the results of previous studies (Smith et al., 1996; James et al., 2002a,d). On the other hand, Xu et al. (2010b) reported that LM marbling scores decreased linearly with increasing DDGS inclusion, but, consistent with the current results, a number of studies failed to note an effect of dietary DDGS on LM marbling scores (Whitney et al., 2006; Xu et al., 2010a; Yoon et al., 2010).

Fatty Acid Composition of Jowl Fat

Previous research has consistently observed that dietary DDGS inclusion increases PUFA, which results in increased carcass fat IV (Stein and Shurson, 2009), both indicative of soft carcass fat and rancidity. In the present study, feeding dietary DDGS resulted in decreased amounts of most SFA and MUFA, and increased PUFA in jowl fat. Particularly, the content of 18:2n-6 was increased by about 3.5% when pigs were fed DDGS. The 18:2n-6 proportion of total fatty acids of DDGS is more than 50%, which may directly result in increased content of C18:2n-6 in jowl fat (Benz et al., 2010, 2011). As expected, IV of jowl fat increased when feeding DDGS in the current study, which agreed with previous research results (Stein and Shurson, 2009; Benz et al., 2010, 2011). In the current study, dietary L-carnitine decreased contents of 18:2n-6 and 20:2 in jowl fat of pigs fed DDGS. In a study evaluating belly fat and lean composition, Apple et al. (2011) observed that the inclusion of 100 mg/kg L-carnitine increased the contents of C18:1 *cis*-9 and all MUFA and decreased 18:2n-6 concentrations in lean layers of pork bellies when pigs were fed diets containing corn oil. They also reported that the C18:2n-6 level and IV of the intermuscular fat layer of pork bellies decreased when pigs were fed 100 mg/kg of L-carnitine. Carnitine palmitoyltransferase-I is considered a rate-limiting enzyme for transporting long-chain fatty acids into the mitochondria and oxidation (McGarry and Brown, 1997). Heo et al. (2000a) suggested that supplemental L-carnitine increased the activity of carnitine palmitoyltransferase-I in the muscles and livers of growing pigs, which may explain the decreased concentrations of C18:2n-6 in pigs fed L-carnitine in this study and in Apple et al. (2011).

In conclusion, dietary DDGS did not affect the growth performance and, as expected, led to greater unsaturation of jowl fat, which led to increased IV. Pigs fed dietary L-carnitine had improved ADG and greater HCW, and dietary L-carnitine reduced 18:2n-4 percentages in jowl fat of pigs fed DDGS diets, with the greatest responses at 50 mg/kg. These findings, along with the results of Apple et al. (2011), indicate that dietary L-carnitine can decrease C18:2n-6 in carcass fat when fed in diets containing feedstuffs high in UFA.

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