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Effects of Dietary L-Carnitine and DDGS on Growth, Carcass Characteristics, and Loin and Fat Quality of Growing-Finishing Pigs[1]

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Summary

A total of 1,104 barrows and gilts (PIC 337 × 1050, initially 80 lb) were used in a 109-d study to evaluate the 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 weight and randomly assigned to 1 of 6 treatments with 7 replications per treatment. Treatments were arranged as a 2 × 3 factorial with main effects of added DDGS (0 or 30% in Phases 1, 2, and 3 and 20% in Phase 4) and L-Carnitine (0, 50, or 100 ppm). Dietary treatments were corn-soybean meal-based and fed in 4 phases. Overall (d 0 to 109), dietary L-Carnitine improved ($P < 0.02$) ADG, which resulted in greater ($P < 0.02$) final BW with the response tending to be linear ($P < 0.07$). For F/G, a DDGS × L-Carnitine interaction (quadratic, $P < 0.01$) was observed. This was the result of pigs fed 50 ppm L-Carnitine, with no DDGS having better F/G than pigs fed 0 or 100 ppm, but in diets containing DDGS, pigs fed 50 ppm L-Carnitine had worse F/G compared with those fed 0 or 100 ppm.

In carcass traits, pigs fed dietary L-Carnitine had greater ($P < 0.02$) HCW compared with those not fed dietary L-Carnitine. Also, increasing dietary L-Carnitine increased carcass weight (quadratic, $P < 0.03$), carcass yield (quadratic, $P < 0.07$), and backfat (quadratic, $P < 0.04$), with the maximum response observed from pigs fed 50 ppm dietary L-Carnitine. In loin quality, feeding dietary L-Carnitine increased ($P < 0.04$) purge loss compared with pigs fed no L-Carnitine, with the response being linear ($P < 0.03$). In jowl fat fatty acid profile, as expected, feeding dietary DDGS increased ($P < 0.001$) Linoleic acid, total polyunsaturated fatty acids (PUFA), the ratio of unsaturated fatty acids to saturated fatty acids, and iodine value (IV) compared with feeding no dietary DDGS; however, feeding L-Carnitine did not alter jowl fatty acid composition.

Feeding dietary L-Carnitine improved ADG and carcass weight, with the maximal response observed at 50 ppm, but dietary L-Carnitine did not affect loin or fat quality.

Key words: carcass characteristics, DDGS, fatty acid, iodine value, L-Carnitine, loin

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Introduction

The primary role of carnitine in intermediary metabolism is tightly related to the β-oxidation of fatty acids. Previous research suggested that feeding dietary L-Carnitine affected metabolism, which stimulated fatty acid oxidation and the utilization of fat for energy (Owen et al., 2001[3]). Although L-Carnitine had mixed effects on growth performance in previous studies, feeding dietary L-Carnitine during the growing-finishing phase resulted in increased longissimus muscle area and decreased backfat thickness of pigs (Owen et al., 1992[4]). Similarly, Owen et al. (1994[5]) suggested that feeding 50 ppm dietary L-Carnitine during the growing-finishing phase provided the optimum response for carcass composition characteristics.

Dried distillers grains with solubles (DDGS) is currently a common ingredient in swine diets; however, it can have negative effects on carcass quality because DDGS contains 10 to 11% fat, a high proportion of which is unsaturated fatty acids. Because L-Carnitine is involved within the energy metabolism in the body, it is theorized that dietary L-Carnitine may increase the dietary energy utilization in DDGS diets fed to pigs and improve fat quality.

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.

Procedures

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

The experiment was conducted in a commercial research finishing barn in southwestern Minnesota. The barn was double-curtain-sided and naturally ventilated. Each pen (10 ft by 18 ft) had completely slatted flooring over a deep pit for manure storage. Each pen was equipped with a 5-hole stainless steel, dry self-feeder and cup waterer for ad libitum access to feed and water. The barn had an automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that was capable of delivering and measuring feed amounts added on an individual pen basis.

A total of 1,104 barrows and gilts (PIC 337 × 1050, initially 80 lb) were used in a 109-d study with 26 pigs per pen and 7 pens per treatment in a randomized design. Pigs were housed mixed gender within pen. Pens were ranked by average pig weight then allotted randomly to 1 of 6 dietary treatments. Dietary treatments were corn-soybean meal-based diets and were fed in 4 phases. Treatments were arranged as a 2 × 3 factorial with main effects of added DDGS (0 or 30% in Phases 1, 2, and 3 and 20% in Phase 4) and L-Carnitine (0, 50, or 100 ppm). All diets were fed in meal form and balanced to the same standardized ileal digestible (SID) lysine:ME ratio within each phase (Table 1).

[3] Owen, K. Q., H. Jit, C. V. Maxwell, J. L. Nelssen, R. D. Goodband, M. D. Tokach, G. C. Tremblay and S. I. Koo. 2001. Dietary L-Carnitine suppresses mitochondrial branched-chain keto acid dehydrogenase activity and enhances protein accretion and carcass characteristics of swine. J. Anim. Sci. 79:3104-3112.
[4] Owen et al., Swine Day 1992, Report of Progress 667, pp. 122-126.
[5] Owen et al., Swine Day 1994, Report of Progress 717, pp. 165-168.

Pigs from each pen were weighed as a group and feed disappearance was determined every 2 wk to determine ADG, ADFI, and F/G. On d 83 of the experiment, the 3 heaviest pigs from each pen (determined visually) were topped and sold in accordance with the farm's normal marketing procedure. These pigs were not included in the carcass data presented. On d 97 of the experiment, 1 barrow and 1 gilt were randomly selected from each pen, tattooed according to gender and pen number for collection of jowl fat and whole loins, and shipped to Sioux-Preme Packing Co. (Sioux City, IA).

After slaughter, the whole boneless loins and approximately 0.5 lb of jowl were collected from the right side of each carcass. The whole loins were individually vacuum-packaged, and each jowl sample was packed in a Ziploc plastic bag. After packing, all loins and jowl samples were transported and stored at the K-State Meat Laboratory at 32 to 38°F.

On d 11 postmortem, loin quality (purge loss, drip loss, shear force, pH, color, and marbling) was evaluated. Purge loss was measured by weighing the whole loin in the packing bag, removing the loin and blotting it dry, and reweighing the loin and dried packing bag. Percentage purge loss was calculated as 100 × (initial loin weight – packing bag weight – final loin weight) / (initial loin weight – packing bag weight). After measuring purge loss, several 1-in. center-cut chops were obtained from each loin. The pH was determined using pH Meter (Model HI9025, HANNA Instruments, Woonsocket, RI). Objective measures of chop color were determined using a HunterLab Miniscan XE Plus spectrophotometer (Model 45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer, Illuminant D65, Hunter Associates Laboratory, Inc., Reston, VA) and reported as L* (lightness, black = 0 to white = 100), a* (redness, a larger value indicates a more red color), and b* (yellowness, a larger value indicates a more yellow color). Visual color and marbling were evaluated by using the National Pork Producers Council's color and marbling standards (NPPC, 1999[6]).

One chop from each loin was weighed and placed into a plastic bag and sealed immediately following fabrication. After storage at 32-38°F 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 frozen (-40°F) on d 11 postmortem. Chops were thawed at 32-36°F for about 24 h then cooked to 104°F, turned, and cooked to a final internal temperature of 158°F in a Blodgett oven (model number DFC-102; The G.S. Blodgett Co., Burlington, VT) preheated to 325°F. 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). The chops were then covered with plastic wrap and refrigerated at 37-39°F for 24 h. Six round cores (0.5-in diameter) were obtained from each chop parallel to the long axis of the muscle fibers using a 0.5-in. corer (G-R Manufacturing Co., Manhattan, KS) attached to an electric drill (Craftsman 3/8-in. Electric Drill; Sears, Hoffman Estates, IL). 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.) attached to an Instron Universal Testing Machine (model 4201, Instron Corp.,

[6] NPPC. 1999. Pork Quality Standards. National Pork Producers Council, Des Moines, IA.

Canton, MA) with a 110-lb compression load cell and a crosshead speed of 250 mm/min. Peak shear force values were recorded in kilograms and the values from the cores were averaged for statistical analysis.

Fat samples were dissected from the jowl and used to analyze fatty acid composition. Iodine value was calculated from the following equation (AOCS, 1998[7]):

Iodine value (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 acids results are represented as a percentage of the total fatty acids in the sample.

At the end of the experiment (d 109), remaining pigs were individually tattooed according to pen number to allow for carcass data collection at the packing plant and data retrieval by pen. All pigs were transported to JBS Swift and Company (Worthington, MN) for processing and data collection. Carcass yield, backfat, lean percentage, and loin depth were collected with pen as the experimental unit.

Analysis of variance was performed by using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). All data were analyzed as a completely randomized design with pen as the experimental unit. Backfat, loin depth, and lean percentage were adjusted to a common HCW. The linear and quadratic L-Carnitine level by DDGS interactions and main effects of DDGS, L-Carnitine, and L-Carnitine level were tested using contrasts. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results and Discussion

During the first phase (d 0 to 28), pigs fed dietary L-Carnitine had better ($P < 0.01$) F/G compared with pigs fed diets without L-Carnitine (Table 2). Additionally, ADFI was reduced (linear, $P < 0.04$) and F/G improved (linear, $P < 0.003$) in pigs fed increasing L-Carnitine. A trend was observed for DDGS × L-Carnitine interaction (quadratic, $P < 0.09$) in F/G. Dietary DDGS had no significant influence on growth critera.

From d 28 to 55, pigs fed dietary L-Carnitine had improved ($P < 0.003$) ADG and ADFI compared with those not fed L-Carnitine, with a linear response for ADG ($P < 0.003$) and a quadratic response for ADFI with increasing L-Carnitine. A DDGS × L-Carnitine interaction (linear, $P < 0.04$) was observed for F/G. Pigs fed increasing L-Carnitine without dietary DDGS had worse F/G, but F/G worsened in the presence of DDGS when fed 50 ppm and improved when 100 ppm was fed. Pigs fed DDGS had worse ($P < 0.01$) F/G than those fed no DDGS.

From d 55 to 83, pigs fed dietary L-Carnitine had greater ($P < 0.03$) ADG and tended ($P < 0.09$) to have greater ADFI compared with pigs fed no dietary L-Carnitine. The improvement in ADG observed from pigs fed increasing L-Carnitine was quadratic ($P < 0.02$), with the maximum response observed at 50 ppm L-Carnitine. A DDGS ×

[7] AOCS. 1998. Official Methods and Recommended Practices of the AOCS method Cd 1c-85. 5th ed. Am. Oil Chem. Soc., Champaign, IL.

L-Carnitine interaction (quadratic, $P < 0.02$) was observed for F/G during this period. This was due to pigs fed 50 ppm dietary L-Carnitine having the best F/G in diets with no DDGS, but having the worst F/G in diets containing 30% DDGS.

In the last phase (d 83 to 109), there was a significant DDGS × L-Carnitine interaction for F/G (quadratic, $P < 0.04$) and a trend for ADG (quadratic, $P < 0.07$). These were the result of pigs fed 50 ppm L-Carnitine no-DDGS-added diets having better ADG and F/G than the other no-DDGS treatments; however, pigs fed 50 ppm L-Carnitine in diets containing DDGS had lower ADG and worse F/G compared with the other added-DDGS treatments. Pigs fed dietary DDGS tended ($P < 0.06$) to increase ADFI compared with no DDGS treatments. A trend (linear, $P < 0.06$) was observed for DDGS × L-Carnitine interaction in ADFI due to pigs fed increasing L-Carnitine in diets with DDGS having increased feed consumption; in contrast, ADFI did not change in diets without DDGS.

Overall (d 0 to 109), feeding dietary L-Carnitine improved ($P < 0.02$) ADG, which resulted in greater ($P < 0.02$) final BW with the responses tending to be linear, ($P < 0.07$). For F/G, a DDGS × L-Carnitine interaction (quadratic, $P < 0.01$) was observed. This was the result of pigs fed 50 ppm L-Carnitine with no dietary DDGS having better feed efficiency than pigs fed 0 or 100 ppm, but in diets containing DDGS pigs fed diets containing 50 ppm L-Carnitine had worse F/G compared with those fed 0 or 100 ppm. Finally, the inclusion of DDGS did not affect growth performance.

For carcass characteristics, no DDGS × L-Carnitine interactions were observed for any carcass traits (Table 3). Pigs fed dietary L-Carnitine had greater ($P < 0.02$) HCW compared with those not fed dietary L-carnitine. Also, increasing the dietary level of L-Carnitine increased carcass weight (quadratic, $P < 0.03$), and backfat (quadratic, $P < 0.04$) and tended to increase carcass yield (quadratic, $P < 0.07$), with the maximum response observed from pigs fed 50 ppm dietary L-carnitine. Pigs fed diets with DDGS tended ($P < 0.09$) to have less loin depth compared with pigs fed no dietary DDGS.

In loin quality, pigs fed dietary L-Carnitine had greater ($P < 0.04$) purge loss compared with pigs fed no L-Carnitine with the response being linear ($P < 0.03$; Table 4). There were DDGS × L-Carnitine interactions for WBSF (quadratic, $P < 0.01$) and visual color (linear, $P < 0.03$). Loins from pigs fed 50 ppm L-Carnitine with DDGS had a lower WBSF value compared with either 0 or 100 ppm with DDGS; however, loins from pigs fed no DDGS changed very little regardless of L-Carnitine level. Feeding dietary DDGS tended ($P < 0.06$) to decrease visual marbling score of loin compared with pigs fed no DDGS. A trend (quadratic, $P < 0.09$) for DDGS × L-Carnitine interaction was observed for b* value (yellowness, a larger value indicates a more red color). Loins obtained from pigs fed 50 ppm L-Carnitine with no DDGS had the greatest b* value, but this same L-Carnitine level had the lowest b* value when fed with dietary DDGS.

For jowl fatty acid characteristics, compared with pigs fed no DDGS diets, feeding dietary DDGS increased ($P < 0.001$) the proportions of C18:2n-6, C18:3n-3, C20:2, C20:4n-6, total PUFA content, the ratio of unsaturated fatty acids to saturated fatty acids, and the calculated IV. In addition, pigs fed DDGS had decreased ($P < 0.001$) C14:0, C16:0, C16:1, C18:0, C18:1 cis-9, C18:1n-7, total monounsaturated fatty

acids, and total saturated fatty acids compared with those not fed DDGS (Table 5). DDGS × L-Carnitine interactions occurred for proportions of C18:2n-6 (linear, $P < 0.01$) and C20:2 (linear, $P < 0.04$). The level of C18:2n-6 and C20:2 were decreased when addition of L-Carnitine in DDGS diets, compared with feeding dietary DDGS without L-carnitine. In addition, the proportion of C20:0 tended (linear, $P < 0.07$) to be increased when increasing inclusion of L-carnitine; however, iodine value and PUFA content of jowl fat were not affected by feeding dietary L-carnitine.

In conclusion, dietary DDGS did not affect the growth performance and, as expected, led to more unsaturation of jowl fat, which led to increased IV. Pigs fed 50 ppm dietary L-Carnitine had improved ADG and carcass weight, but added L-Carnitine did not improve the loin quality and fatty acid saturation. Thus, these data indicate that feeding 50 ppm L-Carnitine in diets for growing and finishing pigs will improve growth rate without altering loin and fat quality.

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

	Dried distillers grains with solubles (DDGS), %							
	Phase 1		Phase 2		Phase 3		Phase 4	
Item	0	30	0	30	0	30	0	20
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	--	0.4	--	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-trace mineral premix	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09
L-Threonine	0.06		0.04	--	0.03	--	--	--
Biolys[2]	0.45	0.55	0.395	0.50	0.35	0.455	0.195	0.265
Phytase[3]	0.01	0.005	0.01	0.003	0.01	0.002	0.01	0.0045
L-Carnitine[4]	--	--	--	--	--	--	--	--
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis								
Standardized ileal digestible (SID) amino acids, %								
Lysine	0.95	0.95	0.82	0.82	0.71	0.71	0.61	0.61
Isoleucine:lysine	62	69	64	71	65	74	73	80
Methionine:lysine	28	33	29	36	30	39	34	41
Met & Cys:lysine	55.8	67	59	73	61	80	70	84
Threonine:lysine	61	63	61	66	63	70	66	75
Tryptophan:lysine	17.0	17.0	17.0	17.0	17.0	17.0	19.0	19.0
Total lysine, %	1.06	1.11	0.92	0.97	0.80	0.86	0.70	0.73
ME, kcal/lb	1,519	1,524	1,521	1,525	1,523	1,527	1,525	1,527
SID lysine: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] Phase 1 diets were fed from 80 to 135 lb. Phase 2 diets were fed from 135 to 185 lb. Phase 3 diets were fed from 185 to 240 lb. Phase 4 diets were fed from 240 to 280 lb.
[2] Biolys contains 50.7% L-lys.
[3] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).
[4] Carniking 10 (Lonza, Inc., Allendale, NJ) replaced corn to provide 50 or 100 ppm L-Carnitine.

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

	No DDGS × carnitine			DDGS × carnitine				Probability, $P <$					
								DDGS × carnitine		Main effects		Carnitine	
	0	50	100	0	50	100	SEM	Linear	Quadratic	DDGS	Carnitine	Linear	Quadratic
d 0 to 28													
ADG, lb	1.99	2.02	2.02	1.98	2.00	1.94	0.03	0.25	0.72	0.22	0.72	0.84	0.28
ADFI, lb	4.68	4.62	4.61	4.65	4.68	4.36	0.08	0.22	0.17	0.29	0.18	0.04	0.30
F/G	2.36	2.29	2.29	2.34	2.34	2.24	0.03	0.61	0.09	0.90	0.01	0.003	0.78
d 28 to 55													
ADG, lb	1.82	1.88	1.90	1.76	1.86	1.88	0.03	0.64	0.70	0.31	0.003	0.003	0.33
ADFI, lb	4.82	5.12	5.21	5.06	5.40	5.12	0.11	0.13	0.28	0.10	0.006	0.04	0.03
F/G	2.66	2.73	2.73	2.88	2.91	2.72	0.05	0.04	0.42	0.01	0.98	0.43	0.16
d 55 to 83													
ADG, lb	1.69	1.82	1.76	1.78	1.84	1.79	0.04	0.48	0.47	0.12	0.03	0.25	0.02
ADFI, lb	5.74	5.77	5.97	5.73	6.08	5.91	0.13	0.86	0.13	0.45	0.09	0.13	0.43
F/G	3.42	3.17	3.40	3.23	3.31	3.29	0.07	0.54	0.02	0.40	0.63	0.72	0.12
d 83 to 109													
ADG, lb	1.65	1.77	1.71	1.76	1.71	1.77	0.05	0.65	0.07	0.32	0.40	0.43	0.74
ADFI, lb	6.05	6.03	6.13	6.51	6.49	5.98	0.16	0.06	0.27	0.06	0.37	0.16	0.51
FG	3.69	3.43	3.60	3.71	3.82	3.38	0.13	0.35	0.04	0.55	0.23	0.12	0.79
d 0 to 109													
ADG, lb	1.79	1.88	1.86	1.82	1.86	1.85	0.02	0.50	0.46	0.83	0.02	0.07	0.07
ADFI, lb	5.28	5.34	5.44	5.43	5.61	5.30	0.09	0.12	0.10	0.20	0.38	0.86	0.15
F/G	2.94	2.84	2.93	2.98	3.02	2.86	0.04	0.24	0.01	0.19	0.20	0.13	0.93
Final Wt, lb	268.5	277.2	274.9	272	275.8	275.6	2.7	0.62	0.46	0.68	0.02	0.07	0.12

[1] A total of 1,104 barrows and gilts (PIC 337 × 1050, initial BW 80 lb) were used in a 109-d experiment with 27 pigs per pen and 7 pens per treatment.

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

								Probability, $P <$					
	No DDGS × carnitine			DDGS × carnitine				DDGS × carnitine		Main effects		Carnitine	
Item	0	50	100	0	50	100	SEM	Linear	Quadratic	DDGS	Carnitine	Linear	Quadratic
Live wt, lb[2]	272.7	276.8	273.9	272.0	276.0	275.8	2.6	0.63	0.75	0.95	0.16	0.35	0.23
HCW, lb	203.5	210.0	205.4	203.9	207.5	207.2	1.9	0.70	0.28	0.95	0.02	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	0.14	0.52	0.07
Backfat, in.[4]	0.66	0.69	0.68	0.65	0.68	0.65	0.01	0.44	0.87	0.14	0.13	0.56	0.04
Loin depth, in.[4]	2.50	2.52	2.50	2.45	2.44	2.45	0.04	0.94	0.74	0.09	0.98	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	0.20	0.56	0.11

[1] A total of 775 pigs were used for obtaining carcass data.
[2] Live weight was obtained at packing plant.
[3] Percentage yield was calculated by dividing HCW by live weight 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 and dried distillers grains with solubles (DDGS) on loin quality

								Probability, $P <$					
	No DDGS × carnitine			DDGS × carnitine				DDGS × carnitine		Main effects		Carnitine	
Item [a,b]	0	50	100	0	50	100	SEM	Linear	Quadratic	DDGS	Carnitine	Linear	Quadratic
Purge loss, %	2.71	3.38	3.47	2.46	2.92	3.45	0.38	0.76	0.63	0.45	0.04	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	0.89	0.34	0.17
WBSF[1], kg	3.16	3.33	3.34	3.55	2.90	3.52	0.16	0.53	0.01	0.74	0.57	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	0.54	0.25	0.43
NPPC color score[2]	3.5	3.5	3.3	3.1	3.4	3.5	0.1	0.03	0.94	0.54	0.16	0.29	0.34
NPPC marbling score[3]	1.9	2.1	1.8	1.7	1.8	1.6	0.2	0.91	0.73	0.06	0.87	0.65	0.27
L* (lightness)[4]	53.6	55.1	54.3	54.5	55.3	55.2	0.6	0.97	0.51	0.21	0.10	0.28	0.14
a* (redness)[5]	8.4	8.1	7.4	7.9	7.4	8.1	0.4	0.12	0.23	0.55	0.27	0.32	0.63
b* (yellowness)[6]	15.5	15.9	14.9	15.7	15.4	15.8	0.3	0.31	0.09	0.51	0.67	0.38	0.49

[a] Values represent the mean of 84 observations.
[b] Above values are adjusted by using gender as a covariate in the model.
[1] Warner-Bratzler Shear Force.
[2] 1 = pale pinkish gray to white, 2 = grayish pink, 3 = reddish pink, 4 = dark reddish pink, 5 = purplish red, 6 = dark purplish red (NPPC, 1999).
[3] Visual scale, which approximates the percentage of intramuscular fat content (NPPC, 1999).
[4] L* = measure of darkness to lightness (black = 0 to white = 100).
[5] a* = measure of redness (a larger value indicates a more red color).
[6] b* = measure of yellowness (a larger value indicates a more yellow color).

Table 5. Effect of dietary L-Carnitine and dried distillers grains with solubles (DDGS) on jowl fatty acid profile

								Probability, $P <$					
	No DDGS × carnitine			DDGS × carnitine				DDGS × carnitine		Main effects		Carnitine	
Item[a,b]	0	50	100	0	50	100	SEM	Linear	Quadratic	DDGS	Carnitine	Linear	Quadratic
Myristic acid (14:0), %	1.45	1.44	1.40	1.35	1.40	1.35	0.03	0.38	0.46	0.007	0.93	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	0.72	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	0.96	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	1.00	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	0.44	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	0.70	0.93	0.36
Vaccenic acid (18:1n-7), %	4.65	4.78	4.65	4.13	4.17	4.18	0.12	0.86	0.59	<0.001	0.61	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	0.74	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	0.68	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	0.20	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	0.50	0.68	0.52
Arachidonic acid (20:4n-6), %	0.10	0.09	0.10	0.11	0.10	0.10	0.003	0.09	0.85	0.001	0.12	0.37	0.12
Total SFA, %[1]	35.12	34.77	34.75	32.07	32.73	32.71	0.35	0.14	0.40	<0.001	0.62	0.69	0.77
Total MUFA, %[2]	49.88	50.33	49.98	45.93	46.31	45.66	0.53	0.72	0.90	<0.001	0.71	0.87	0.31
Total PUFA, %[3]	13.73	13.72	13.92	20.61	19.67	20.24	0.55	0.60	0.48	<0.001	0.54	0.87	0.35
Total TFA, %[4]	0.34	0.32	0.36	0.39	0.34	0.40	0.01	0.69	0.28	0.02	0.43	0.45	0.01
UFA:SFA ratio[5]	1.82	1.85	1.84	2.08	2.02	2.02	0.03	0.13	0.37	<0.001	0.52	0.52	0.87
PUFA:SFA ratio[6]	0.39	0.40	0.40	0.65	0.60	0.62	0.02	0.35	0.39	<0.001	0.38	0.62	0.38
Iodine value, g/100g[7]	66.50	66.85	66.89	74.66	73.33	73.95	0.64	0.38	0.29	<0.001	0.54	0.80	0.44

[a] Values represent the mean of 84 observations.
[b] Percentage of total fatty acid content.
[1] Total saturated fatty acids = {[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.
[2] Total monounsaturated fatty acids = {[14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] +[C24:1]}, where the brackets indicate concentration.
[3] Total polyunsaturated fatty acids = {[C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n6]}, where the brackets indicate concentration.
[4] Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.
[5] UFA:SFA ratio = [Total MUFA + Total PUFA]/Total SFA.
[6] PUFA:SFA = Total PUFA/Total SFA.
[7] Calculated as 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.