Effects of betaine on growth, carcass characteristics, pork quality, and plasma metabolites of finishing pigs[1,2,3]

J. O. Matthews, L. L. Southern[4], A. D. Higbie, M. A. Persica, and T. D. Bidner

Department of Animal Science, Louisiana State University Agricultural Center, Baton Rouge, 70803-4210

ABSTRACT: An experiment was conducted to determine the effect of dietary betaine (0, 0.125, 0.250, or 0.500%) on growth, carcass traits, pork quality, plasma metabolites, and tissue betaine concentrations of crossbred finishing pigs. Four replications of three pigs (two barrows and one gilt) each were used for each treatment. The basal diet contained 0.85 (69 to 88 kg BW) or 0.65% Lys (88 to 115 kg BW). Overall ADG and gain:feed were not affected ($P > 0.10$) by betaine, but overall ADFI was decreased (quadratic, $P < 0.05$; 0 vs betaine, $P < 0.01$) by betaine; pigs fed 0.250% betaine had the lowest ADFI. Loin muscle area, average backfat, dressing percentage, percentage lean, total fat, lean:fat, and leaf fat weight were not affected ($P > 0.10$) by betaine. Tenth-rib backfat thickness was decreased (quadratic, $P < 0.05$; 0 vs betaine, $P < 0.05$); pigs fed 0.250% betaine had the lowest 10th-rib backfat thickness. Carcass length was increased (linear, $P < 0.05$; 0 vs betaine, $P < 0.10$) as the level of betaine was increased. Fat-free lean, lean gain per day, ham weight, ham fat-free lean, and ham percentage lean were increased (quadratic, $P < 0.10$), but percentage fat, total ham fat, percentage ham fat, and butt-fat thickness were decreased (quadratic, $P < 0.10$); these traits were respectively highest or lowest in pigs fed 0.250% betaine. Thaw loss and 24-h pH were increased (quadratic, $P < 0.10$; 0 vs betaine, $P < 0.05$) and cook loss was decreased (linear, $P < 0.05$) in pigs fed betaine. The CIE L* value for the biceps femoris was decreased (quadratic, $P < 0.10$; 0 vs betaine, $P < 0.10$); pigs fed 0.250% betaine had the lowest CIE L* value. Subjective color, firmness-wetness, marbling, percentage moisture and bound water of the loin muscle, and shear force were not affected ($P > 0.10$) by betaine. Betaine was not detectable (< 0.07 mg/g) in the loin muscle of pigs fed 0% betaine, but betaine was detectable and relatively constant in pigs fed 0.125, 0.250, or 0.500% betaine (0.22, 0.17, and 0.21 mg/g, respectively). Plasma urea N, total protein, albumin, triglycerides, and HDL cholesterol concentrations were not affected ($P > 0.10$). Plasma total cholesterol (linear, $P < 0.10$) and NEFA (quadratic, $P < 0.10$) were increased in pigs fed betaine. Betaine improved carcass traits when provided at 0.250% of the diet and improved some aspects of pork quality.

Key Words: Betaine, Carcass Traits, Growth, Meat Quality, Pigs, Pork

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Introduction

Much of the research with betaine in finishing pigs has evaluated effects on growth and carcass traits, and usually only one level of betaine has been fed. The level of betaine used most often has been 0.125% (Webel, 1994; Cera and Schinckel, 1995; Matthews et al., 1998). However, levels as low as 0.10% (Smith et al., 1994, 1995) and as high as 1.0% (Øverland et al., 1999) have been used.

Currently, the swine industry is focused on improving pork quality. Very little research has been conducted evaluating the effects of betaine on pork quality. Øverland et al. (1999) reported no effects on sensory quality of pork from pigs fed 1.0% betaine. Matthews et al. (1998) reported that subjective color of the loin muscle in pigs fed 0.125% betaine was decreased, but subjective marbling and firmness-wetness were not affected.

Bagnasco et al. (1986) reported high levels of betaine in cells of the inner medulla of the kidney during conditions of antidiuresis, which may indicate that betaine plays an important role in intracellular osmotic balance. Furthermore, betaine has been shown to improve osmotolerance and cryotolerance of *Listeria monocyto-*

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[4]Correspondence: 204 J. B. Francioni Bldg. (phone: 225-578-3449; fax: 225-578-3604; E-mail: lsouthern@agctr.lsu.edu).

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genes when subjected to salt and cold stress conditions (Ko et al., 1994). Thus, these osmo-protectant properties of betaine could affect pork quality, assuming that betaine is accumulated in muscle tissue of swine.

Therefore, the purpose of this study was twofold: 1) to determine whether betaine is accumulated in muscle tissue by feeding graded levels of betaine and 2) to determine how these graded levels of betaine affect pork quality, as well as growth and carcass traits.

Materials and Methods

General

The experiment was approved by the Louisiana State University Agricultural Center Animal Care and Use Committee.

Forty-eight crossbred barrows and gilts with an average initial weight of 69 kg were allotted to four dietary treatments on the basis of weight, and ancestry was equalized across treatments in a randomized complete block design. Four replications of three pigs (two barrows and one gilt) per replicate were used for each treatment. The treatment diets included a corn-soybean meal basal (Table 1) supplemented with 0, 0.125, 0.250, or 0.500% betaine (Betafin S6, Finnsugar Bioproducts, Schaumburg, IL). The finishing phase was divided into two periods. The early-finishing diets containing 0.85% lysine were fed from 69 to 88 kg BW, and the late-finishing diets containing 0.65% lysine were fed from 88 to 115 kg BW. Both the early- and late-finishing diets were formulated to meet or exceed the nutrient requirements of finishing pigs (NRC, 1998). Feed and water were provided for ad libitum consumption, and pigs were housed in a curtain-sided building with 1.5- × 3.0-m pens and concrete slotted floors. Pigs and feeders were weighed every 2 wk for calculation of weight gain, feed intake, and feed efficiency.

Table 1. Percentage composition of the basal diets, as-fed basis

Item	Early finishing	Late finishing
Ingredient		
Corn	78.004	85.277
Soybean meal (48% CP)	17.869	10.473
Monocalcium phosphate	0.813	0.935
Limestone	1.090	1.091
Sodium bentonite	0.500	0.500
Trace minerals[a]	0.100	0.100
Selenium premix[b]	0.050	0.050
Salt	0.500	0.500
Vitamins[c]	0.375	0.375
Lysine·HCl	0.150	0.150
Cornstarch[d]	0.549	0.549
Calculated composition		
CP, %	15.26	12.36
Lysine, %	0.85	0.65
Tryptophan, %	0.17	0.12
Threonine, %	0.56	0.44
Total sulfur AA, %	0.53	0.45
Ca, %	0.60	0.60
P, %	0.50	0.50
Choline, mg/kg	972	815
ME, kcal/kg	3,273	3,271

[a]The trace mineral premix provided the following per kilogram of diet: Zn, 127 mg; Fe, 127 mg; Mn, 20 mg; Cu, 12.7 mg; I, 0.80 mg, as zinc sulfate, ferrous sulfate, manganese sulfate, copper sulfate, and ethylenediamine dihydriodide, respectively, with calcium carbonate as the carrier.

[b]Provided 0.3 mg of Se per kilogram of diet.

[c]The vitamin premix provided the following per kilogram of diet: vitamin A, 8,267 IU; vitamin D_3, 2,480 IU; vitamin E, 66 IU; vitamin B_{12}, 0.05 mg; d-biotin, 0.33 mg; menadione, 6.20 mg; niacin, 66 mg; Ca d-pantothenic acid, 37 mg; riboflavin, 10 mg; folic acid, 2.48 mg; thiamine, 3.31 mg; pyridoxine, 3.31 mg; ascorbic acid, 0.08 mg.

[d]Betaine was added at the expense of cornstarch. The 0, 0.125, 0.250, and 0.500% betaine diets had analyzed betaine concentrations of 0, 0.101, 0.211, or 0.483% and 0, 0.126, 0.279, or 0.479% for the early and late finishing diets, respectively.

Plasma Collection and Analyses

Blood samples were collected via the anterior vena cava at experiment initiation and on d 35 of the experiment. Pigs were held without feed for 16 h before bleeding. After collection of blood, the samples were placed on ice for 2 h, then centrifuged for 15 min at 1,500 × *g* at 4°C. Plasma was collected and frozen (–20°C) until subsequent analyses for urea N, total protein, albumin, triglycerides, cholesterol, HDL cholesterol, and NEFA. The sample collected at the initiation of the experiment was analyzed and used as a covariate for statistical analyses of all plasma metabolites. Urea N, total protein, and albumin concentrations were determined by the methods of Laborde et al. (1995). Nonesterified fatty acid concentrations (NEFA-C Kit, ACS-ACOD Method; Wako Chemicals USA, Richmond, VA; McCutcheon and Bauman, 1986), total cholesterol (Sigma kit #352-100; Sigma Chemical Co., St. Louis, MO), and triglycerides (Sigma Kit #339-20) were determined using enzymatic-colorimetric procedures. The HDL cholesterol fraction was isolated using a HDL kit (Sigma Kit #352-1) and then HDL cholesterol was determined using a cholesterol kit (Sigma Kit #352-100).

Carcass Evaluation

Pigs were killed by weight block; each weight block was killed as it approached target slaughter weight (113 to 118 kg). Pigs were transported to the Louisiana State University Agricultural Center Meats Laboratory for slaughter and killed by electrical stunning followed by exsanguination. Hot carcass (for determination of dressing percentage) and leaf fat weights were collected. Carcass measurements and values from total body electrical conductivity (**TOBEC**; Model MQI-27: Meat Quality Inc., Springfield, IL) analysis (for calculation of fat-free lean and fat content in the carcass) were obtained after a 20-h chill at 2°C. The carcass measurements (obtained from the left side of the carcass) included loin muscle area, first-rib backfat thickness, 10th-rib backfat thickness, last-rib backfat thickness,

last-lumbar vertebrae backfat thickness, carcass length, and muscle score. The left side of the carcass was used for TOBEC analysis (Higbie, 1997). The psoas muscle was removed from the right side of the carcass, cleaned of any adhering intermuscular fat, and weighed.

Loin muscle area was determined by tracing the loin muscle surface area at the 10th-rib, and area was determined with a compensating polar planimeter. Tenth-rib backfat thickness was determined by measuring the fat thickness at the 10th rib, three quarters of the lateral length of the loin muscle perpendicular to the outer skin surface. Average backfat was determined by averaging the backfat thickness at the first rib, last rib, and last lumbar vertebrae. Butt-fat thickness of the ham was measured beneath the femur bone in the butt face from the interior edge of the s.c. fat on a straight line to the outer skin surface and perpendicular to the outer skin surface. Dressing percentage was calculated using the following equation: [(hot carcass weight ÷ final BW) × 100]. Fat-free lean and total fat were determined by TOBEC analysis using the equations of Higbie (1997). The equation used to calculate kilograms of fat-free lean was as follows: [–2.164 + (0.172 × carcass length) + (0.164 × peak TOBEC value) – (0.742 × carcass temperature)] × 2; (R^2 = 0.93). The equation used to calculate kilograms of total fat was as follows: [–9.528 + (0.660 × cold carcass side weight) + (1.181 × 10th-rib backfat) – (0.132 × peak TOBEC value) + (0.465 × carcass temperature)] × 2; (R^2 = 0.90). Percentage lean in the carcass was calculated by the equation [(fat-free lean ÷ hot carcass weight) × 100] and percentage fat in the carcass was calculated by the equation [(total fat ÷ hot carcass weight) × 100]. Lean gain per day was determined using the equation [(fat-free lean – initial lean) ÷ number of days on trial]. Initial lean was determined using the equation of Brannaman et al. (1984): [–1.59 + (0.44 × initial BW)]. This equation was developed for determining initial lean of 15- to 50-kg pigs; however, it was used in this experiment to determine initial lean of pigs initially weighing 69 kg. The equation used to calculate kilograms of ham fat-free lean was as follows: [2.738 + (0.121 × peak ham TOBEC value) – (0.089 × ham temperature)]; (R^2 = 0.95). The equation used to calculate kilograms of total ham fat was as follows: [–2.393 – (0.090 × peak ham TOBEC value) + (0.671 × ham weight) + (0.072 × ham temperature) + (0.276 × butt-fat thickness)]; (R^2 = 0.84).

Pork Quality Evaluation

Approximately 45 min and 24 h after slaughter, pH and temperature were taken from the right side of the carcass in the loin muscle between the 10th and 11th ribs. The pH of loin muscle was determined using a hand-held pH meter (Model 2000; VWR Scientific Products Co., South Plainfield, NJ) fitted with a spear-tipped electrode (Catalog # P-05658-60; Cole-Parmer Instrument Co., Vernon Hills, IL). After collection of all carcass data, two 2.54-cm chops were collected from the 9th and 10th ribs. Immediately after collection of the chops, CIE L*, a*, and b* values (determined using the CIELAB space with a D65 illuminant) were obtained from three orientations on the 10th-rib chop using a Minolta spectrophotometer (Model CM-508d; Minolta Corporation, Ramsey, NJ). The pork quality scores (color, marbling, and firmness-wetness) also were determined on the 10th-rib chop using the guidelines of the NPPC (1991). Water-holding capacity (bound water) was determined in triplicate on samples from the 9th-rib chop using a press method (Wierbicki and Deatherage, 1958).

The 10th-rib chop was vacuum-sealed and frozen for subsequent analyses of thaw loss, cook loss, and shear force. While still sealed in vacuum bags, chops were weighed to determine total weight after thawing at 2°C for 18 h. Initial chop weight was calculated as total weight – empty bag weight. The chop was then removed from the vacuum bag, blotted with paper towels to remove excess surface moisture, then weighed to determine the blotted-chop weight. Thaw loss was determined as initial chop weight – blotted-chop weight. Loin chops were then cooked on a Farberware Open-Hearth Broiler (Farberware Co., Bronx, NY). The chops were cooked to an internal temperature of 35°C, turned to the uncooked side, and cooked to an internal temperature of 70°C. After cooking, chops were allowed to cool to room temperature, blotted to remove excess surface moisture, and weighed for cooked-chop weight. Cook loss was determined as blotted-chop weight – cooked-chop weight. Total loss was calculated as thaw loss + cook loss. Thaw loss, cook loss, and total loss weights were then expressed as a percentage of initial chop weight.

After weights for cook loss were obtained, chops were placed in an unsealed vacuum bag and refrigerated at 2°C for 20 h. Four 1.27-cm cores taken parallel to the muscle fibers were removed from each chop. Cores were sheared perpendicular to the grain of the muscle fiber using an Instron Model 4501 Universal Testing Instrument (Instron, Canton, MA) fitted with a Warner-Bratzler shearing device with a cross-head speed of 100 mm/min.

Tissue Betaine Analysis

Approximately 45 min postmortem, tissue samples were collected from the loin muscle for all treatments and from the ham (biceps femoris) of pigs fed the 0.125% level of betaine. After collection, the sample was immediately wrapped in aluminum foil and parafilm, then frozen using Dry Ice and acetone. Samples were stored at –30°C until shipment for analysis of betaine concentrations. Analysis for betaine was conducted by the Cultor Technology Center, Kirkkonummi, Finland. Betaine concentrations were determined using the methods outlined by Rajaklä and Paloposki (1983) with the following modification: HPLC conditions were 0.004 *M* $Ca(NO_3)_2$ with a flow rate of 0.6 mL/min.

Statistical Analysis

Data were analyzed by analysis of variance procedures (Steel and Torrie, 1980) using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC) as a randomized complete block design. Carcass data (with the exception of pork quality data) were analyzed with final body weight as a covariate. Time of pH and temperature collection in reference to kill time were used as covariates for the pH and temperature data, respectively. Initial plasma data served as a covariate for all plasma data. Orthogonal single-degree-of-freedom contrasts were used to determine linear and quadratic effects. An additional contrast statement was used to compare the 0% betaine level vs the three added levels of betaine (0 vs betaine). The pen of pigs served as the experimental unit for all data.

Results

Overall ADG, gain:feed, and gain:ME were not affected ($P > 0.10$) by betaine (Table 2). Overall ADFI and ME intake were decreased (quadratic, $P < 0.05$; 0 vs betaine, $P < 0.01$) by betaine; pigs fed the 0.250% level of betaine had the lowest ADFI and ME intake. Lean gain:ME intake was increased in pigs fed the 0.250% level of betaine (quadratic, $P < 0.05$).

Loin muscle area, average backfat thickness, dressing percentage, psoas muscle weight, muscle score, percentage lean, total fat, lean:fat, and leaf fat weight were not affected ($P > 0.10$) by dietary betaine (Table 3). Tenth-rib backfat thickness was decreased (quadratic, $P < 0.05$; 0 vs betaine, $P < 0.05$) in pigs fed betaine; pigs fed 0.250% betaine had the lowest 10th-rib backfat thickness. Carcass length was increased (linear, $P < 0.05$; 0 vs betaine, $P < 0.10$) as dietary betaine increased. Fat-free lean (quadratic, $P < 0.05$) and lean gain per day (quadratic, $P < 0.10$) were increased and percentage fat was decreased (quadratic, $P < 0.10$); pigs fed 0.250% betaine had the highest amount of fat-free lean and lean gain per day and lowest percentage fat. Similarly, ham weight (quadratic, $P < 0.10$), ham fat-free lean (quadratic, $P < 0.05$), and ham percentage lean (quadratic, $P < 0.05$) were increased; pigs fed 0.250% betaine had the highest ham weight, ham fat-free lean, and ham percentage lean, but total ham fat (quadratic, $P < 0.05$), percentage ham fat (quadratic, $P < 0.05$), and butt-fat thickness (quadratic, $P < 0.05$) were decreased, and pigs fed 0.250% betaine had the lowest total ham fat, percentage ham fat, and butt-fat thickness.

Forty-five-minute pH and carcass temperature were not affected ($P > 0.10$) by betaine; however, 24-h pH was increased in pigs fed betaine (quadratic, $P < 0.05$; 0 vs betaine, $P < 0.01$; Table 4). Twenty-four-hour carcass temperature was decreased (quadratic, $P < 0.10$), and pigs fed 0.250% betaine had the lowest 24 h temperature. Thaw loss was increased (quadratic, $P < 0.10$; 0 vs betaine, $P < 0.05$) but cook loss was decreased (linear, $P < 0.05$) as dietary betaine increased. The CIE L* for the biceps femoris was decreased (quadratic, $P < 0.10$; 0 vs betaine, $P < 0.10$); pigs fed 0.250% betaine had the lowest CIE L* value. Total loss (thaw + cook loss) was not affected ($P > 0.10$) by betaine. Subjective (NPPC, 1991) and objective (Minolta) color assessments (except biceps femoris CIE L* value), loin muscle percentage moisture and percentage bound water, and shear force were not affected ($P > 0.10$) by betaine supplementation.

Levels of tissue betaine in the loin muscle were not detectable in pigs not fed betaine (Table 4). In pigs fed betaine, tissue betaine concentrations were detected, but they did not differ regardless of dietary betaine level. Tissue betaine concentrations in the ham of pigs fed 0.125% betaine were comparable to those found in the loin muscle.

Plasma urea N, total protein, albumin, triglycerides, and HDL cholesterol concentrations and HDL:total cholesterol were not affected ($P > 0.10$; Table 5) by betaine. Plasma total cholesterol (linear, $P < 0.10$) and NEFA concentrations (quadratic, $P < 0.10$) were increased in pigs fed betaine. Pigs fed the 0.125 and 0.250% levels of betaine had the highest NEFA concentrations.

Discussion

Although ADG was not significantly affected by betaine, gain:feed was not increased as might be expected

Table 2. Effect of betaine on growth performance of finishing pigs[a]

	Betaine, %				
Item	0	0.125	0.250	0.500	SEM
Daily gain, kg/d	0.84	0.81	0.77	0.77	0.03
Daily feed, kg/d[bcd]	3.12	2.82	2.74	2.84	0.07
Gain:feed, kg:kg	0.270	0.288	0.279	0.271	0.008
Daily ME intake, Mcal/d[bcd]	10.22	9.23	8.98	9.28	0.24
Gain:ME, g:Mcal	83	88	85	83	2
Lean gain:ME, (g:Mcal)/d[c]	23.5	24.2	28.7	22.2	1.5

[a]Data are means of four replicates of three pigs per replicate. Average initial and final body weights were 69 and 115 kg, respectively.
[b]Linear effect, $P < 0.05$.
[c]Quadratic effect, $P < 0.05$.
[d]0% betaine vs 0.125, 0.250, and 0.500% betaine effect, $P < 0.01$.

Table 3. Effect of betaine on carcass characteristics of finishing pigs[a]

Item	Betaine, %				SEM
	0	0.125	0.250	0.500	
Carcass lean and fat measurements					
Loin muscle area, cm^2	44.05	42.73	44.37	41.58	1.61
Tenth-rib backfat, cm[bcd]	2.53	2.42	2.07	2.21	0.08
Average backfat, cm	2.82	2.77	2.69	2.76	0.07
Dressing percentage	74.26	73.12	75.07	74.31	1.04
Carcass length, cm[be]	81.20	81.58	82.47	82.69	0.38
Psoas muscle, kg	0.51	0.52	0.51	0.50	0.01
Muscle score	2.37	2.37	2.52	2.41	0.06
Fat-free lean, kg[cf]	41.58	41.23	44.17	41.33	0.61
Percentage lean[f]	49.02	49.60	51.56	48.64	1.16
Lean gain per day, g[g]	229	222	265	207	12
Total fat, kg[f]	26.64	26.66	24.24	25.93	0.73
Percentage fat[fg]	31.23	31.60	28.12	30.26	0.61
Lean:fat, kg:kg	1.67	1.62	1.84	1.66	0.07
Leaf fat, kg	1.27	1.46	1.22	1.48	0.10
Ham lean and fat measurements					
Ham weight, kg[g]	9.98	10.21	10.29	10.02	0.11
Fat-free lean, kg[cf]	6.26	6.36	6.79	6.23	0.13
Percentage lean[cf]	62.50	62.29	66.09	62.23	0.90
Total fat, kg[cf]	2.17	2.26	1.91	2.23	0.06
Percentage fat[cf]	21.88	22.23	18.47	22.20	0.73
Butt-fat thickness, cm[c]	1.67	1.74	1.43	1.72	0.05

[a]Data are means of four replicates of three pigs per replicate. All data were analyzed with final body weight as a covariate. The covariate was significant ($P < 0.10$) in the carcass length, psoas muscle, muscle score, carcass and ham fat-free lean, lean gain per day, carcass total fat, and ham weight data.
[b]Linear effect, $P < 0.05$.
[c]Quadratic effect, $P < 0.05$.
[d]0% betaine vs 0.125, 0.250, and 0.500% betaine effect, $P < 0.05$.
[e]0% betaine vs 0.125, 0.250, and 0.500% betaine effect, $P < 0.10$.
[f]Determined using total body electrical conductivity analysis.
[g]Quadratic effect, $P < 0.10$.

due to the reduction in feed intake. Betaine previously has been reported to decrease feed intake of gilts fed 0.125% betaine (Cera and Schinckel, 1995; Matthews et al., 1998), and our data are in agreement. However, other reports have indicated that betaine had no effect on feed intake (Webel, 1994; Casarin et al., 1997; Kitt et al., 1999), or that feed intake may be increased or decreased depending on the lysine:calorie ratio or energy level of the diet (Haydon et al., 1995).

Carcass traits were consistently affected by the 0.250% level of betaine. Pigs fed 0.250% betaine had a 20% reduction in 10th-rib backfat thickness, a 6% increase in fat-free lean, a 14.6% increase in lean gain per day, and a 10.5% reduction in percentage carcass fat. Betaine has been reported to decrease backfat thickness (Cadogan et al., 1993; Casarin et al., 1997) and increase carcass lean in pigs (Casarin et al., 1997; Cromwell et al., 1999), and our data are in agreement. However, other reports have indicated that 0.125 or 1.0% betaine does not affect carcass traits (Webel, 1994; Matthews et al., 1998; Øverland et al., 1999), and Haydon et al. (1995) reported that backfat thickness and loin muscle area may be increased or decreased in pigs fed 0.10% betaine depending on the lysine:calorie ratio or energy level of the diet. In addition, carcass length was increased linearly in pigs fed betaine, which is in agreement with Matthews et al. (1998), who reported that 0.125% betaine increased carcass length. Lean and fat measurements of the ham were similar to those of the carcass, with improved lean and fat characteristics for every ham trait measured in pigs fed 0.250% betaine.

One of the primary goals of this study was to determine whether dietary betaine supplementation would increase muscle tissue betaine, and, if so, whether dietary betaine would affect pork quality. Pigs fed 0% betaine had no detectable tissue betaine concentration, but pigs supplemented with betaine (regardless of the level of betaine) had detectable betaine concentrations in the loin muscle. Thus, betaine supplementation of the diet did result in detectable levels of betaine in muscle tissue.

Considering that betaine was detectable in the muscle tissue of pigs fed betaine, it is possible that it may affect pork quality, and our data are somewhat supportive of this statement. Improvements were observed for 24-h pH and CIE L* value of the biceps femoris. Thaw loss was increased in pigs fed betaine but cook loss was decreased, resulting in no effect on total loss (thaw + cook loss). Very little literature exists concerning the effects of betaine on pork quality. Subjective color of the loin muscle has been reported to be decreased in

Table 4. Effect of betaine on pork quality of finishing pigs[a]

Item	Betaine, % 0	0.125	0.250	0.500	SEM
45-min pH[b]	6.24	6.18	6.06	6.01	0.09
45-min temperature, C[b]	40.28	40.08	40.36	40.19	0.25
24-h pH[bc]	5.44	5.55	5.53	5.55	0.02
24-h temperature, C[bd]	1.83	1.86	1.57	1.91	0.08
Color[e]	2.08	2.21	2.04	2.33	0.12
Firmness-wetness[e]	2.79	2.75	2.60	3.00	0.18
Marbling[e]	1.92	1.92	1.65	1.77	0.19
Loin muscle (LM)					
CIE L*	55.55	54.84	56.18	54.97	1.07
CIE a*	2.19	1.59	2.42	1.64	0.77
CIE b*	11.68	11.43	12.51	11.89	0.76
Biceps femoris					
CIE L*[df]	53.62	51.43	50.03	52.03	1.11
CIE a*	4.65	4.21	3.87	4.14	0.46
CIE b*	12.87	12.07	11.96	11.99	0.61
LM moisture, %	73.95	74.27	74.31	74.02	0.24
LM bound water, %	80.05	78.60	77.21	80.84	1.44
Thaw loss, %[dgh]	7.94	8.54	9.79	9.51	0.40
Cook loss, %[g]	23.20	23.01	22.20	19.86	0.93
Total loss, %	31.14	31.56	31.99	29.37	1.15
Shear force, kg	2.44	2.83	2.73	2.68	0.18
Tissue betaine					
Loin muscle, mg/g[i]	ND	0.22	0.17	0.21	0.02
Ham, mg/g	—	0.16	—	—	—

[a]Data are means of four replicates of three pigs per replicate.
[b]Time of data collection in reference to kill time was used as a covariate for pH and temperature measurements. The covariate was significant ($P < 0.10$) in the 24-h temperature data.
[c]Linear effect, $P < 0.01$; quadratic effect, $P < 0.05$; 0% betaine vs 0.125, 0.250, and 0.500% betaine effect, $P < 0.01$.
[d]Quadratic effect, $P < 0.10$.
[e]Scores were taken on the interface of the 10th-rib chop according to the guidelines of the NPPC (1991).
[f]0% betaine vs 0.125, 0.250, and 0.500% betaine effect, $P < 0.10$.
[g]Linear effect, $P < 0.05$.
[h]0% betaine vs 0.125, 0.250, and 0.500% betaine effect, $P < 0.05$.
[i]Data were analyzed without the 0% betaine treatment; ND indicates that betaine concentrations were not detectable (< 0.07 mg/g).

pigs fed 0.125% betaine. However, betaine had no effect on subjective marbling and firmness-wetness of pigs fed 0.125% betaine or on sensory quality of pigs fed 1.0% betaine (Matthews et al., 1998; Øverland et al., 1999). Although these effects of betaine on pork quality in the current experiment are promising, more research is necessary.

Matthews et al. (1998) reported that 0.125% betaine decreased serum urea N in fed pigs. Although plasma urea N was not significantly affected in the current

Table 5. Effect of betaine on plasma metabolites of finishing pigs[a]

Item	Betaine, % 0	0.125	0.250	0.500	SEM
Urea N, mg/dL	8.27	7.55	7.62	7.60	0.37
Total protein, g/L	61.49	62.66	61.97	60.91	1.64
Albumin, g/L	32.40	31.97	30.65	32.00	0.89
Triglycerides, mg/dL	37.99	38.55	35.69	38.87	1.38
Total cholesterol, mg/dL[b]	73.91	75.99	78.75	80.90	2.47
HDL cholesterol, mg/dL	38.83	45.23	36.42	41.20	4.29
HDL:total cholesterol	0.54	0.61	0.46	0.49	0.05
NEFA, μEq/L[c]	480	650	637	523	63

[a]Data are means of four replicates of three pigs per replicate. The initial plasma sample was used as a covariate for analysis of all data. The covariate was significant ($P < 0.10$) in the urea N and NEFA data.
[b]Linear effect, $P < 0.10$.
[c]Quadratic effect, $P < 0.10$.

experiment, it was numerically lower in pigs fed all levels of betaine. Plasma total protein and albumin were not affected in the present study. Matthews et al. (1998) reported that serum total protein and albumin were affected by betaine, but the effects were dependent on the energy and crude protein level of the diet. The level of ME used in the present study was similar to that in the low-energy diet used by Matthews et al. (1998), but the lysine level used was different, which could partially explain the discrepancy in the total protein and albumin data. Matthews et al. (1998) and Øverland et al. (1999) reported no effect of betaine on serum or plasma cholesterol or NEFA concentrations; however, our data indicate that betaine increased plasma cholesterol, and plasma NEFA were increased in pigs fed 0.125 and 0.250% betaine. Øverland et al. (1999) also reported that betaine did not affect plasma triglycerides, and our data are in agreement. Furthermore, plasma HDL cholesterol and HDL:total cholesterol were not affected by betaine. The effects of betaine on plasma NEFA and cholesterol would seem to indicate that betaine affects fat metabolism; however, the lack of response in triglycerides would indicate otherwise.

Implications

Addition of 0.250% betaine to the diet of finishing pigs may result in improved leanness and carcass quality, which are beneficial to the swine industry. The effects of betaine on pork quality are important to consumers as well. Further research should be conducted to determine the impact dietary betaine may have on carcass leanness and pork quality.

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