FATS AND PROTEINS RESEARCH FOUNDATION, INC.

Final Report: Final Report Submitted: September 1, 2011

Submitted to: Fats and Proteins Research Foundation, Inc.
801 North Fairfax Street, Suite 205
Alexandria, Virginia 22314

Project Title: Effect of Phase-Feeding Beef Tallow on Quality Characteristics of Subcutaneous Fat and Fresh Pork Bellies from Growing-Finishing Pigs fed Dried Distillers Grains with Solubles

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Projected Started: April 1, 2010 Projected Completed: July 30, 2011

INSTRUSTY SUMMARY

Introduction

Soft pork fat in fresh pork bellies has become a major concern of pork processors. Soft pork bellies have been associated with fabrication difficulties, reduced product yields, unattractive bacon slices, reduced product shelf-life, and subsequent consumer discrimination. The increased incidence of soft pork fat and bellies has been attributed to the elevation of the polyunsaturated fatty acid (PUFA) composition of diets by feeding large amounts of dried distillers' grains with solubles (DDGS). There does not appear to be a cost-effective, nutritional method of reversing the deleterious effects of feeding highly polyunsaturated fat sources, along with DDGS, on pork fat and belly firmness issues.

Previous research indicated that almost 70% of the fatty acid composition of pork fat was established in the first 17.4 kg (50 lbs) of body weight gain (Apple et al., 2009b). Moreover, the half-life of linolenic acid in porcine subcutaneous fat is approximately 300 days (Anderson et al., 1972). Thus, it was hypothesized that feeding a more saturated fat source during the growing phases would establish more saturated pork fat depots, so, when large amounts of DDGS and/or polyunsaturated fat sources were fed in later dietary phases, the negative effects of elevating dietary PUFA on belly firmness would be negligible.

Specific Objectives

Compare the effects of feeding 5% beef tallow during the grower phases to feeding 5% beef tallow during the finisher phases on: 1) live performance and carcass characteristics; 2) quality characteristics of subcutaneous fat and fresh pork bellies; and 3) bacon quality and palatability.

Summary

Results of this study indicate that phase-feeding beef tallow, a saturated fat source, in place of yellow grease, a polyunsaturated fat source, to pigs fed diets formulated with DDGS had little to no impact on live pig performance or pork carcass characteristics. The concentrations of all saturated and monounsaturated fatty acids were greater in backfat from pigs fed 5% beef tallow throughout the study, as well as pigs fed 5% beef tallow in the finishing phases than backfat from pigs fed 4.7% yellow grease throughout the study. In addition, the percentage of polyunsaturated fatty acids and calculated iodine value (IV) were reduced in backfat and jowl fat samples by feeding beef tallow in the finishing phases.

There was a tendency, however, for fresh bellies from pigs fed yellow grease throughout the study to be softer than bellies from pigs fed beef tallow throughout the study. Moreover, the fatty acid composition of the belly fat from pigs fed beef tallow in the finisher phases was quite similar to that of pigs fed beef tallow across the entire trial, whereas bellies from pigs fed beef tallow in the growing phases had a fatty acid profile similar to that of bellies from pigs fed yellow grease across all growing and finishing phases. Conversely, there was no effect of any phase-feeding beef tallow on yields of commercially-processed bacon, mechanical bacon tenderness, or any bacon palatability attribute. Therefore, results of this study would indicate that feeding beef tallow in the finishing phases rather than in the growing phases may prevent fat quality, and more specifically fresh belly quality, issues that are routinely observed when growing-finishing pigs are fed high amounts of dried distillers' grains with soluble (DDGS) or poor quality greases and oils.

Scientific Abstract

Crossbred pigs (n = 216) were used to test the effects of phase-feeding beef tallow (BT) and yellow grease (YGr) to growing-finishing swine fed dried distillers grains with soluble (DDGS) on live performance, carcass, belly, and bacon quality characteristics, and fatty acid composition of various fat depots. Pigs were blocked by initial BW (26 ± 5.3 kg) and gender before allotment to pens (6 pigs/pen), and pens (6 pens/block) were allotted randomly to 1 of 6 dietary treatments: 1) grower and finisher diets formulated with 4.7% YGr fed during all 5 feeding phases (NC); 2) diets containing 5.0% BT fed during all 5 feeding phases (PC); 3) diets containing 5.0% BT fed during the first 2 phases with 4.7% YGr fed the last 3 phases (BT12); 4) diets formulated with 5.0% BT fed during the first 3 phases and diets with 4.7% YGr fed the last 2 phases (BT123); 5) diets containing 4.7% YGr fed during the first 3 phases followed by diets with 5.0% BT fed the last 2 finishing phases (BT345); or diets with 4.7% YGr fed during the first 3 phases followed by the 5.0% diets fed the last 2 phases (BT45). All dietary treatments were formulated with 30% dried distillers grains with solubles (DDGS) during phases 1, 2, and 3, 15% DDGS during phase 4, and no DDGS during phase 5. Pigs were slaughtered at an average BW of 124.1 kg, and samples of backfat and jowl fat were collected prior to carcass fabrication. Fresh belly quality data were collected on the left-sided bellies, whereas right-sided bellies were processed at a commercial bacon plant. Then, USDA-certified No. 1 slices were collected for cooking characteristics and sensory panel evaluations. Over the entire feeding trial, pigs fed BT345 tended to have greater ($P = 0.10$) ADG than the NC, BT123, and BT45 treatments, and pigs fed PC tended to consume less ($P = 0.09$) feed than all other dietary treatments. There was no ($P \geq 0.23$) effect of fat inclusion on dressing percentage, carcass lean percentage, backfat, and LM depth. Weight percentages of palmitic acid (16:0), all SFA, oleic acid (18:1c9), and all MUFA were greater

($P < 0.01$) in backfat from pigs fed the PC and treatments formulated with BT in the late finisher phases than backfat from pigs fed the NC. Proportions of linoleic acid (18:2*n*6), all PUFA, and IV were greater ($P < 0.01$) in backfat and jowl fat samples from NC-fed pigs in comparison to PC-fed pigs. Bellies from the NC-fed pigs were softer ($P \leq 0.05$) than bellies from PC-fed pigs; however, instrumentally measured belly firmness was not ($P \geq 0.38$) different among treatments. Concentrations of 16:0, stearic acid, and 18:1c9, as well as all SFA and all MUFA, were greater ($P < 0.01$) in bellies from PC-fed than NC-fed pigs. In contrast, proportions of 18:2*n*6, all PUFA, and IV were greater ($P < 0.01$) in belly fat from NC-fed pigs in comparison to PC-fed pigs. However, yield of commercially-processed bacon ($P \geq 0.14$), mechanical bacon tenderness ($P \geq 0.70$), and bacon palatability attributes ($P \geq 0.55$) were not affected by the dietary treatments. Results indicate that feeding BT during the finishing phases, rather than in the growing phases, had a greater impact on the fatty acid composition of pork fat, but phase-feeding tallow had little to no effect on live pig performance, fresh belly firmness, or cooked bacon palatability.

Key words: Bacon, Beef Tallow, Bellies, Dried distillers' grains with solubles, Swine, Yellow grease

Introduction

Soft pork fat and soft bellies have become the primary pork quality defects being addressed by today's pork processors, based largely on the economic losses associated with fabrication difficulties, reduced product yields, unattractive processed products (especially bacon), reduced product shelf-life, and subsequent consumer discrimination of these products (Averette Gatlin et al., 2002; Apple et al., 2009c). Even though pork fat has been shown to be inversely related to pork carcass leanness, the increased incidence of soft pork fat and pork bellies is the consequence of elevating the PUFA composition of diets fed

growing-finishing swine by feeding large quantities of dried distillers grains with solubles (DDGS) or low levels (≤ 5%) of poor-quality greases and/or oils (Benz et al., 2010; Apple et al., 2011).

It has been suggested that the complete removal of polyunsaturated dietary fat sources from the late-finisher diet(s) would reverse the negative effects of these fat sources on pork fatty acid composition and firmness. However, results from Apple et al. (2009b) implied that the complete removal of a polyunsaturated fat source from the late-finishing diet(s) would have few beneficial effects, whereas replacing the polyunsaturated fat source with a saturated fat source would have only minimal impacts on pork fat quality. Furthermore, replacement of DDGS with either beef tallow (BT) or choice white grease during the last 26 d before slaughter failed to reverse the effects of DDGS on pork quality (Stevens et al., 2009).

To date, there does not appear to be a cost-effective, nutritional method of reversing the deleterious effects of feeding highly polyunsaturated fat sources, especially DDGS, on pork fat and belly firmness issues. Previous research indicated that almost 70% of the fatty acid composition of pork fat was established in the first 17.4 kg of BW gain (Apple et al., 2009a, b, c); therefore, it was hypothesized that feeding a more saturated fat source during the growing phases would establish more saturated pork fat depots; so, when large amounts of DDGS and/or polyunsaturated fat sources were fed in later dietary phases, the negative effects of elevating dietary PUFA on belly firmness would be negligible. Therefore, the objectives of this experiment were to test the effects of phase-feeding BT on live pig performance, pork carcass composition, fatty acid compositions of subcutaneous fat depots, and fresh belly and bacon quality characteristics.

Experimental Procedures

Pig husbandry and all experimental protocols were in accordance with standard operating procedures for swine experiments and approval (protocol no. 10041) issued by the University of Arkansas Interdepartmental Animal Care and Use Committee prior to initiating this study.

Animals and Diets

Crossbred pigs (n = 216) from the mating of GPK-35 females (Newsham Choice Genetics, Des Moines, IA) and line 380 sires (PIC North American, Hendersonville, TN), were blocked by BW (26 ± 5.3 kg) and gender into 6 blocks of 36 pigs/block. Pigs within blocks were allotted randomly to pens (6 pigs/pen) with equal numbers of barrows and gilts, and pens (6 pens/block) were assigned randomly to 1 of 6 dietary treatments (Table 1): corn-soybean meal-based grower and finisher diets formulated with 4.7% yellow grease (YGr) fed during all 5 feeding phases (NC); 2) corn-soybean meal-based grower and finisher diets formulated with 5.0% beef tallow (BT) fed during all 5 feeding phases (PC); 3) diets containing 5.0% BT fed during the first 2 feeding phases and diets containing 4.7% YGr fed during the last 3 phases (BT12); 4) diets formulated with 5.0% BT fed during the first 3 phases and diets containing 4.7% YGr fed during the last 2 phases (BT123); 5) diets containing 4.7% YGr fed during the first 2 feeding phases and diets with 5.0% BT fed during the last 3 phases (BT345); or 6) diets with 4.7% YGr fed during the first 3 phases and diets with 5.0% BT fed during the last 2 phases (BT45). Pigs were fed a 5-phase diet with transition from grower-I to grower-II, grower-II to finisher-I, finisher-I to finisher-II, and finisher-II to finisher-III when the mean BW of each block was 42.7, 61.6, 81.1, and 101.0 kg, respectively. All dietary treatments were formulated to represent commercial inclusion levels of dried distillers grains with solubles (DDGS), with 30% DDGS during phases 1, 2, and 3, 15% DDGS during phase 4, and no DDGS during phase 5. All diets were isocaloric and

isolysinic, and formulated to meet, or exceed, NRC (1998) requirements for growing-finishing pigs (Table 2). Additionally, samples of each barrel of BT and YGr (Darling International Inc., Irving, TX), as well as diet samples from each feeding phase, were collected for fatty acid analysis.

Pigs were housed in a curtain-sided building with completely slatted floors. Each 1.5 × 3.0-m pen was equipped with a single-hole feeder and wean-to-finish waters for ad libitum access to diets and water. Individual pig BW, as well as pen feed disappearance, were measured for each feeding phase to calculate ADG, ADFI, and G:F.

Pig Slaughter and Carcass Data Collection

At an average BW of 124.1 kg, all pigs were transported approximately 8 h (720 km) to a commercial pork packing plant (Cargill Meat Solutions, Beardstown, IL) and slaughtered according to humane, industry-accepted procedures after a 6-h lairage period. Tenth rib fat and LM depths were measured on-line with a Fat-O-Meater (FOM) probe inserted between the 10^{th} and 11^{th} ribs at a distance approximately 7 cm from the midline, and HCW and FOM-estimated fat-free lean yield were recorded. Then, the carcasses were subjected to a 24-h conventional blast-chilling system. Approximately 4 h after entering the chilling system, fat samples from the jowl and midline at the last lumbar vertebrae were collected, individually identified, packaged, and transported on dry ice back to the University of Arkansas for fatty acid analysis. Additionally, bellies from right and left sides of each carcass were individually identified, and, during fabrication, fresh pork bellies (IMPS #408) were captured, placed in combos, and transported under refrigeration to the University of Arkansas Red Meat Research Abattoir for quality data collection.

Belly Quality Data Collection

Upon arrival at the abattoir, the length, width, thickness (mean of cranial, caudal, dorsal, and ventral measurements), and temperature (belly firmness was only measured on bellies with temperatures between 1.7 and 2.8 ° C) were measured on the left-side bellies. Subjective belly firmness was measured according to the bar-suspension (flop) method of Theil-Cooper et al. (2001), where the distance between belly ends was measured when the length of the belly was suspended perpendicular (skin-side up and skin-side down) to a 1.9-cm-diameter. bar. Belly firmness angle (the upper angle of the isosceles triangle formed by suspending the belly across the bar) was also calculated using the equation of Whitney et al. (2006): $\cos^{-1}$ ([{0.5 x L^2} – D^2] / {0.5 x L^2}); where L is the belly length and D is the distance between belly ends when suspended perpendicular to the bar. Additionally, instrumental color (L*, a*, and b* values) of the belly fat was measured with a Hunter Miniscan XE (Hunter Associate Laboratories, Reston, VA) using illuminant C and a 10° standard observer, as well as subjective Japanese fat color scores. A 3.8-cm-diameter strip from the anterior end of each belly was removed, vacuum-packaged, and stored at -20°C to be used to objectively measure belly firmness. Then, approximately 250 g of subcutaneous fat from the area between the first and second teats of each belly was removed and stored in Whirl-Pak bags (NASCO, Fort Atkinson, WI) at -20°C for fatty acid analysis.

Objective belly firmness was measured according to the Instron puncture test of Trusell et al. (2011). Briefly, belly strips were thawed at 1°C for 48 h before each belly strip was separated into 4 equal-length portions. Temperature of each belly section was measured (belly firmness was only measured on sections with temperatures between 1.7 and 2.8°C) before thickness of each section was measured with calipers to determine belly thickness. Subsequently, belly sections were placed skin-side down on a lower flat plate, and were punctured to 65% of their specific thickness with an Instron testing machine

(model 4466; Instron Corp., Canton, MA) equipped with a 10-cm-long, 1.3-cm-diameter, rounded tip puncturing bar, a 50-kg load cell, and a crosshead speed of 100 mm/min.

Bacon Data Collection

Bellies from the right side of each carcass were transported under refrigeration to a commercial bacon processing plant (Wright Brand Foods, Vernon, TX), where each belly was identified during curing and thermal processing. Weights were recorded at all stages of processing (prior to skinning, following brine injection, following smoking, and following slicing) and yields were calculated as a percentage of the green belly weight. Sliced bacon from each belly was captured, individually boxed, and transported under refrigeration back to the University of Arkansas Red Meat Research Abattoir for cooking characteristics and sensory panel evaluations of cooked bacon.

Upon arrival at the abattoir, sliced bacon from the center of each slab was identified and subsequently vacuum-packaged and stored at -20°C for cooking characteristics (n = 6 slices/belly) and sensory panel evaluations (n = 15 slices/belly). Bacon was thawed at 1°C for 24 h, removed from vacuum packaging, placed on paper plates, and L*, a*, and b* values of the bacon fat were determined from a mean of 3 random readings made with a Hunter Miniscan XE (Hunter Associate Laboratories, Reston, VA) using illuminant D65 and a 10° standard observer. Bacon was then weighed and cooked in a commercial oven (Zephaire E model; Blodgett Oven Co., Burlington, VT) preheated to 204.4°C for 9 min. After removal from the oven, bacon was blotted dry with paper towels and weighed, and the difference between precooked and cooked weights was used to calculate cooking loss percentage. A 6.0-cm section of bacon was subsequently removed from the center of the slices, and each section was subsequently sheared once with a 10-blade, Allo-Kramer shear force device attached to an Instron Universal Testing Machine (model 446; Instron Corp.,

Canton, MA) with a 200-kg tension/compression load cell and a crosshead speed of 100 mm/min. Shear force values of the cooked bacon were determined from a mean of 4 sections.

Bacon Sensory Panel Evaluations

For each of the 18 sensory panel sessions, 12 slices of bacon from one pig from each of the dietary treatments was thawed for 48 h at 1°C in vacuum-packaged bags, placed randomly across cooking racks (9 slices/rack), and cooked in convection ovens preheated to 218.3°C for 17 min. Immediately after removal from the oven, bacon was blotted dry with paper towels and an approximate 6.0-cm bacon section was removed from the center of each slice and served warm to each panelist in a random order. Panelists were provided unsalted saltine crackers, distilled, drinking water, and apple juice or apple slices to cleanse their palates between samples. Traits evaluated by the sensory panel included initial crispiness, bacon flavor intensity, saltiness, sustained chewiness, oiliness, and off-flavor intensity (1 = extremely crisp, bland, bland, crumbly, abundant, and abundant to 8 = extremely soft, intense, salty, chewy, none, and none).

Fatty Acid Analysis

Duplicate 5-g fat samples from the jowl, backfat, and belly, as well as feed samples, were weighed and placed in 30-mL beakers, and reweighed. Beakers were then placed into vacuumed-flasks attached to the manifold of a Labconco freeze-dryer (Model 4.5, Labconco Corp., Kansas City, MO) with a temperature setting of -50°C and a vacuum of less than 10 mm of Hg. Fat and feed samples were freeze-dried for 72 h before duplicate 30-mg, freeze-dried samples, as well as samples from each barrel of BT and YGr, were subjected to direct transesterification by incubating in 2.0 mL of 0.2 *M* methanolic KOH in 16 × 125-mm screwcap tubes at 50 °C for 30 min with vortex-mixing 2 to 3 times/min until dissolved

(Murrieta et al., 2003). Tubes were allowed to cool to room temperature, and 1 mL of saturated NaCl was added to each tube. Then, 2 mL of hexane containing 0.5 mg/mL of an internal standard (methyl tridecanoic acid [13:0]) were added to tubes, tubes were vortexed, and subsequently centrifuged for 5 min at 1,100 × *g* at 22° C to separate phases.

Fatty acid methyl esters (FAME) were transferred to GLC vials that contained 1.0-mm bed of anhydrous sodium sulfate. Separation of FAME was achieved by GLC (Model 5890 Series II GC with automatic sample injector [HP-7673] with HP-3365software; Hewlett-Packard, Avondale, PA) equipped with a 100-m capillary column (0.25-mm internal diameter; Model 2560 Fused Silica Capillary; Supelco Inc., Bellefonte, PA) and a He as the carrier gas (20 cc/sec). Oven temperature was maintained at 150 °C for 5 min, ramped at 4 °C/min to 194 °C for 15 min, and then ramped at 2.5 °C/min to 235 °C for 16.25 min, whereas injector and detector temperatures were maintained at 250 °C. Qualification of peaks was accomplished using purified standards obtained from Supelco (Bellefonte, PA; 37 component mix) and individual acids from Nu-Check Prep (Elysian, MN) and Martreya (Pleasant Gap, PA).

The total proportion of minor SFA was the sum of the weight percentages of capric (10:0), lauric (12:0), myristic (14:0), pentadecanoic (15:0), margaric (17:0), and arachidic (20:0) acids, whereas the total proportion of all SFA was calculated by adding the total proportion of minor SFA with the proportions of palmitic (16:0) and stearic (18:0) acids. The total proportion of all MUFA was calculated by summing the weight percentages of myristoleic (14:1), palmitelaidic (16:1*t*), palmitoleic (16:1*c*), 10-*trans*-heptadecenoic (17:1*t*), all 18-carbon fatty acids with a single *trans* double bond (total 18:1*t*), oleic (18:1c9), vaccenic (18:1c11), and gadoleic (20:1c11); however, the total proportion of minor MUFA excluded 18:1c9. Additionally, the total percentage of all PUFA included linoleic (18:2*n*-6),

total conjugated linoleic (CLA; including the isomers 18:2c9t11, 18:2c9c11; 18:2c10c12; and 18:2t9t11), γ-linolenic (18:3*n*-6), α-linolenic (18:3*n*-3), eicosadienoic (20:2), dihomo-γ-linolenic (20:3*n*-6), eicosatrienoic (20:3*n*-3), arachidonic (20:4*n*-6), docosapentaenoic (22:5*n*-3), and docosahexaenoic (22:6*n*-3), whereas the total proportion of minor PUFA excluded 18:2*n*-6. The PUFA:SFA was calculated by dividing the total proportion of PUFA by the total proportion of SFA, whereas, the iodine value (IV) of each section was calculated according to the AOCS (1998) equation: (0.95 × [∑16:1]) + (0.86 × [∑18:1]) + (1.732 × [∑18:2]) + (2.616 × [∑18:3]) + (0.785 × [20:1]), where brackets indicate the weight percentage concentration.

Statistical Analyses

Data were analyzed as a randomized complete block design, with blocks based on initial BW and pen as the experimental unit. Analysis of variance was achieved by using the mixed models procedure (SAS Inst. Inc., Cary, NC). The lone fixed effect in all statistical models was the dietary treatment, whereas initial BW block was considered a random effect in all statistical models. In the ANOVA for the cooked bacon sensory data, panelist within session was also included in the model as a random effect. Least-squares means were computed and separated statistically using pairwise *t*-tests (PDIFF option) when a significant *F*-test ($P \leq 0.05$) was observed. In addition, specific contrasts were included in all data analysis to specifically compare: 1) YGr vs. BT diets (NC vs. PC); 2) BT vs. YG in phases 1 and 2 (BT12 vs. BT345); 3) BT vs. YG in phases 1, 2, and 3 (BT123 vs. BT45); and 4) feeding BT in the early feeding phases vs. BT in the late feeding phases (BT12 and BT123 vs. BT345 and BT45).

Results and Discussion

The BT had an approximate 1.4-fold greater SFA content than the YGr, and the percentages of palmitic (16:0) and stearic (18:0) acids were especially greater in the BT than YGr (Table 3). On the other hand, the YGr had an almost 5-fold greater concentration of PUFA than the BT, and the proportions of linoleic (18:2*n*6) and α-linolenic acid (18:3*n*3) acids in the YGr being approximately 585 and 614% greater than the BT, respectively. Moreover, the IV calculated according to the AOCS (1998) equation were 44.88 and 68.46 mg/g for the BT and YGr, respectively.

Even though diets were formulated to be isocaloric, those formulated with 5.0% BT contained 7.2 (grower-II diets) to 8.5 (finisher-I diets) percentage units more total SFA than diets formulated with 4.7% YGr (Table 4). The proportion of total MUFA, specifically oleic acid (18:1*c*9), varied little among the diets; however, diets formulated with YGr had almost ⅓ more PUFA than those formulated with BT. Additionally, the IV of the grower-I, grower-II, finisher-I, finisher-II, and finisher-III diets containing YGr were 14.4, 15.2, 17.3, 14.3, and 14.7 mg/g greater, respectively, than the same phase diets formulated with BT.

Growth and Carcass Characteristics

Live pig performance (ADG, ADFI, and G:F) was not affected by the dietary treatments during grower-I ($P \geq 0.15$), grower-II ($P \geq 0.44$), finisher-I ($P \geq 0.54$), and finisher-III ($P \geq 0.11$) phases; however, ADFI was reduced ($P = 0.04$) in pigs fed BT throughout the study (PC) when compared to pigs in the BT12, BT123, and BT45 treatments during the finisher-II phase (Table 5). Furthermore, pigs fed YGr during the first 3 feeding phases gained more ($P = 0.04$) in finisher-II phase than pigs fed BT during the first 3 phases. Also during the finisher-II phase, PC-fed pigs tended to consumer less ($P = 0.06$) feed than NC-fed pigs. Over the entire feeding trial, pigs fed BT345 tended to have greater ($P = 0.10$) ADG than the

NC, BT123, and BT45 treatments, and the ADG of BT45-fed pigs was less than that of BT12- and BT345-fed pigs. In addition, pigs fed PC tended to consume less ($P = 0.09$) feed than all other dietary treatments, as well as having a tendency for greater ($P = 0.07$) G:F than pigs fed NC.

In general, increasing the energy density of swine diets by adding fat and greases typically reduces ADFI, modestly improves ADG, and typically results in substantial improvements in G:F without deleterious effects on pork carcass characteristics (Greeley et al., 1964; Stahly et al., 1981; De la Llata et al., 2001). Greeley et al. (1964) reported that formulating swine diets with 4, 8, and 12% animal tallow increased ADG and decreased DM consumption, as well as DM required per unit of gain, as the level of tallow was increased in the diet. The inclusion of lard and tallow in the diets of growing-finishing pigs has led to consistent improvements in feed conversion efficiency (Leibbrandt et al., 1975; Leskanich et al., 1997). And, even though Stahly et al. (1981) and Eggert et al. (2007) failed to observe an effect of feeding high-fat diets on ADG, reductions in feed intake and increases in G:F were still noted in pigs fed the high-fat finishing diets. It should be noted, however, that there is information suggesting that formulating swine diets fats or greases does not alter the growth rate and feed conversion efficiency in growing-finishing swine (Engel et al., 2001; Averette Gatlin et al., 2002; Bee et al., 2002), which concurs with the results of the present experiment.

As expected, neither slaughter and hot carcass weights, dressing percentage, 10th rib fat depth, LM depth, nor lean muscle yields were affected ($P \geq 0.23$) by the imposed dietary treatments (Table 6). Including 5% BT in the first 2 feeding phases reduced ($P = 0.03$) LM depths when compared to carcasses of pigs fed 4.7% YGr during the first 2 phases.

A number of studies have failed to detect an effect of including fat in swine diets on slaughter weight (Greeley et al., 1964; De la Llata et al., 2001; Averette Gatlin et al., 2002), let alone differences in slaughter weights, HCW, or dressing percentages between the feeding saturated vs. polyunsaturated fat sources (Kouba and Mourot, 1999; Engel et al., 2001; Bee et al., 2002). Even though Miller et al. (1990) reported that feeding finishing pigs diets formulated animal fat increased backfat depths compared to pigs fed diets devoid of added fat, most research has not demonstrated an effect of dietary fat inclusion (De la Llata et al., 2001; Averette Gatlin et al., 2002; Eggert et al., 2007) or differences among dietary fat sources (Bee et al., 1999, 2002; Engel et al., 2007) on pork fat thickness. Moreover, similar to results of the present study, neither LM depth nor area have been shown to be altered by dietary fat inclusion (Smith et al., 1999; De la Llata et al., 2001; Averette Gatlin et al., 2002).

Fatty Acid Composition

Saturated fatty acids. Backfat and jowl SFA profiles are presented in Table 7. The backfat and jowl fat of PC-fed pigs had greater ($P \leq 0.02$) proportions of all SFA than backfat and jowl fat samples from NC-fed pigs. Furthermore, the percentages of 16:0 ($P < 0.01$), as well as minor SFA ($P \leq 0.03$), including myristic acid (14:0), pentadecanoic acid (15:0), and margaric acid (17:0), were greater in jowl fat and backfat of pigs fed PC diets than fat samples from NC-fed pigs. Conversely, percentages of arachidic acid (20:0) were greater ($P \leq 0.02$) in both backfat and jowl of pigs fed the NC diet rather than the PC diet. Even though the proportion of 18:0 was greater ($P = 0.01$) in jowl fat from pigs fed YGr during the first 3 phases (BT45) than pigs fed BT during the same beginning phases (BT123). Furthermore, backfat from BT45-fed pigs had greater ($P \leq 0.03$) proportions of all SFA, and more specifically 16:0 and 18:0, than backfat from BT123-fed pigs. On the other hand, jowl fat

from pigs fed BT during the first 3 feeding phases had more ($P < 0.01$) 15:0 and 17:0 than jowl fat from pigs fed YGr during the first 3 phases. The 20:0 percentage in backfat samples was also greater ($P < 0.01$) in BT12-fed pigs than in BT345-fed pigs. In addition, pigs fed BT in the late feeding phases had more ($P \leq 0.04$) total SFA and 16:0 in the backfat, and more ($P \leq 0.04$) 15:0 and 17:0 in jowl fat, than pigs fed BT in the early feeding phases.

Monounsaturated fatty acids. Both backfat and jowl fat from PC-fed pigs had greater ($P \leq 0.01$) percentages of all MUFA, 18:1*c*9, and the minor MUFA, including myristoleic (14:1), palmitelaidic (16:1*t*), palmitoleic (16:1*c*), and heptadecenoic (17:1*t*) acids, than fat samples from NC-fed pigs ((Table 8). The proportion of all 18:1*t* fatty acids were greater ($P = 0.01$) in jowl and backfat samples from pigs fed PC than NC diets, but the proportion of *cis*-vaccenic acid (18:1c11) was only elevated ($P = 0.02$) in backfat of PC-fed than NC-fed pigs. Additionally, backfat pigs fed YGr during the first 2 feeding phases had greater ($P \leq 0.02$) percentages of all MUFA, 18:1*c*9, 14:1, 16:1*t*, and 17:1*t* than backfat from pigs fed BT during the first 2 phases. Feeding YGr during the first 2 feeding phases also increased ($P \leq 0.04$) the proportions of the minor MUFA, including 16:1*c* and 18:1c11, in both the jowl and backfat when compared to pigs fed BT during the first 2 feeding phases. Interestingly, the jowl fat from pigs fed BT during the first 3 phases had more ($P \leq 0.05$) 16:1*t* and all 18:1*t* fatty acids than jowl fat from pigs fed YG during these 3 feeding phases.

Pigs fed BT during the later phases had greater ($P < 0.01$) of all MUFA, and particularly 18:1c9, in backfat than pigs fed BT during the early phases; however, the percentage of 14:1 in backfat was actually greater in pigs fed BT during the early phases than during the late feeding phases (Table 8). In addition, the proportion of all minor MUFA and 16:1*t* were greater ($P \leq 0.04$) in backfat and jowl fat when BT was fed in the late than early feeding phases, whereas including BT in diets fed during the late phases increased (*P*

≤ 0.04) 16:1*c* and 18:1*c*11 in jowl fat when compared to including YGr in diets fed during the late phases.

Polyunsaturated fatty acids. Proportions of total PUFA, including 18:2*n*6, 18:3*n*3, eicosadienoic acid (20:2), dihomo-γ-linolenic acid (20:3*n*-6), and docosapentaenoic acid (22:5*n*-3) were greater ($P \leq 0.04$) in the backfat and jowl fat of pigs fed NC than PC-fed pigs (Table 9). In addition, the backfat from NC-fed pigs had greater ($P \leq 0.02$) proportions of minor PUFA, and particularly arachidonic acid (20:4*n*-6), than backfat from pigs fed PC. Conversely, backfat and jowl fat from pigs fed BT during all 5 feeding phases has more ($P < 0.01$) total CLA, including the 18:2c9t11 isomer, than in samples from pigs fed YGr throughout the study.

Although backfat and jowl fat from BT12-fed pigs had more ($P < 0.01$) 18:3*n*3 than that of BT345-fed pigs, only backfat from pigs fed BT during the first 2 feeding phases had greater ($P < 0.01$) proportions of all PUFA and 18:2*n*6 than backfat from pigs fed YGr during the first 2 phases (Table 9). Furthermore, the backfat from pigs fed YGr during the last 2 finishing phases (BT123) contained more ($P \leq 0.03$) total PUFA, including 18:2n6, 18:3n3, 20:2, and 22:5, than backfat from pigs fed BT during the last 2 feeding phases (BT45). As expected, however, the proportion of all CLA isomers was greater ($P \leq 0.01$) in backfat and jowl fat from pigs fed BT during either the last 2 or last 3 feeding phases (BT345 and BT45, respectively) when compared to fat samples from pigs fed YGr during the entire finishing period (BT12) or the last 2 finishing phases(BT123). Interestingly, feeding BT across the early feeding phases elevated ($P < 0.01$) the percentages of all PUFA, 18:2*n*6, 18:3*n*3, 20:2, and 22:5 in only backfat samples in contrast to feeding BT during the late feeding phases.

The PUFA:SUFA and IV. Percentages of other, unidentified fatty acids in backfat did not ($P \geq 0.17$) among the dietary treatments; however, jowl fat from PC-fed pigs

had more ($P < 0.01$) unidentified fatty acids than that from NC-fed pigs, and jowl fat from pigs fed BT during the first 3 feeding phases had greater ($P < 0.01$) percentages of other fatty acids than jowl fat from pigs fed YGr during the first 3 phases (Figure 1). The PUFA:SFA (Figure 2) and IV (Figure 3) were greatest ($P < 0.01$) in the backfat from NC-fed than PC-fed pigs, and backfat from pigs fed BT during the late feeding phases (BT345 and BT45) had lower ($P < 0.01$) PUFA:SFA and IV than that of pigs fed BT during the early phases (BT12 and BT123). Additionally, both PUFA:SFA and IV of jowl samples were greater ($P < 0.01$) in pigs fed NC when compared to PC-fed pigs; yet, phase-feeding BT had no appreciable effect on PUFA:SFA ($P \geq 0.42$) or IV ($P \geq 0.59$) of jowl fat samples.

It is generally accepted that the fatty acid composition of pork depends largely on the fatty acid composition of the diet; thus, the fatty acid profile of pork fat can be altered rather quickly, especially when pigs consume diets formulated with a polyunsaturated fat source (Warnants et al., 1999; Averette Gatlin et al., 2002). When swine diets were formulated with BT, backfat and LM intramuscular fat have increased percentages of SFA (Bee et al., 1999, 2002; Mitchaothai et al., 2007) and MUFA (Miller et al., 1990; Morel et al., 2006) and decreased percentages of PUFA (Monahan et al., 1992; Pfalzgraf et al., 1995). Moreover, Apple et al. (2009a) reported that the subcutaneous fat from pigs fed 5% BT had greater percentages of SFA and MUFA and lesser percentages of PUFA than pigs fed 5% soybean oil. In the current study, 14:0 and 16:0 were greater in fat from pigs fed BT the entirety of the trial compared to fat from pigs fed diets formulated with YGr throughout the feeding trial. Stearic acid (18:0) percentages were not altered by the addition of 5.0% BT in swine diets, regardless of feed phase, in the present diet, which is consistent with the findings of Monahan et al. (1992) and Morel et al. (2006); yet, Bee et al. (1999, 2002) and Pfalzgraf et

al. (1995) reported that the proportion of 18:0 was actually greater in backfat from pigs BT, especially when compared to feeding diets formulated with soybean oil.

In agreement with several published studies, the subcutaneous fat depots from growing-finishing pigs fed diets formulated with BT had greater 18:1c9 concentrations compared to fat from pigs fed oils and greases (Bee et al., 1999, 2002; Morel et al, 2006). Additionally, Pfalzgraf et al. (1995) reported that C18:1c11 and C20:1 percentages were not affected when BT was formulated in swine diets, which is similar to the present results. Furthermore, concurring with previous research where BT was fed to growing-finishing swine, concentrations of the prevalent PUFA, C18:2*n*-6, were found to be depressed in a number of fat depots (Pfalzgraf et al., 1995; Morel et al., 2006). Conversely, no differences in concentrations of C18:3*n*-6 (Monahan et al., 1992; Bee et al., 1999; Mitchaothai et al., 2007) and C22:6*n*-3 (Mohanan et al., 1992; Bee et al., 1999) were found in the fat from pigs consuming diets formulated with BT. Similar to the results of Bee et al. (1999) dietary inclusion of BT did increase the proportion of CLA in both backfat and jowl fat samples.

When diets contain DDGS or fat sources high in PUFA, backfat and LM intramuscular fat contain greater PUFA percentages (Eggert et al., 1998) and lesser percentages of SFA (Weber et al., 2006) and MUFA (Apple et al., 2009b; Xu et al., 2010a,b). Similar to fat from pigs fed YGr throughout the grower and finisher phases, total SFA content was reduced in backfat from pigs fed 5% poultry fat or 5% choice white grease (Eggert et al., 1998; Weber et al., 2006). Seerley et al. (1978) observed that feeding poultry fat reduced 18:1c9 concentrations in LM intramuscular fat; however, Weber et al. (2006) reported that total MUFA was greater in fat from pigs supplemented with choice white grease compared to fat from pigs fed diets devoid of added fat. Moreover, Seerley et al. (1978), Eggert et al. (1998) and Apple et al. (2009b) reported that feeding poultry fat (comparable fatty acid

composition to the YGr used in the current study) increased the proportions of all PUFA, and particularly 18:2*n*6, when compared to control diets or diets formulated with BT. Additionally, Xu et al. (2010b) found that with increasing DDGS in grower-finisher diets resulted in increases in total PUFA, including C18:2*n*-6, C18:3*n*-3, C20:2, and C20:3*n*-6, with simultaneous decreases in total SFA (particularly 16:0 and 18:0) and total MUFA (especially 16:1*c*, C18:1*c*9, and C20:1*c*11) in backfat. Furthermore, percentages of 16:0, 18:0, and 18:1*c*9 were decreased, and 18:2*n*-6 percentages were increased, linearly with increasing dietary inclusion levels of DDGS (Benz et al., 2010; Leick et al., 2010). More importantly, these authors noted that the increases in PUFA that occur when pigs are fed up to 30% DDGS was associated with deteriorating carcass fat quality (Benz et al., 2010; Leick et al., 2010).

Apple et al. (2009b, c) demonstrated that almost 75% of the change in the fatty acid composition of backfat and carcass composite samples occurred during the first 17.4 kg of BW gain. Therefore, it was hypothesized that feeding BT during the early growing phases would produce a more saturated fatty acid composition and allow greater amounts of DDGS or polyunsaturated fat sources to be fed during the finisher phases. Yet, results of this study indicated that feeding BT during the last 2 or last 3 feeding phases actually produced more saturated subcutaneous fat depots, comparable to the fatty acid composition of fat from pigs fed BT throughout all 5 grower-finisher phases.

Belly Characteristics

Bellies from the NC-fed pigs were softer ($P \leq 0.05$) than bellies from the PC-fed pigs, as indicated by greater belly flop distances and flop angles, regardless of how bellies were oriented to the bar (Table 10). Furthermore, there was a tendency for bellies from pigs fed

BT during the first 3 feeding phases to be firmer ($P = 0.06$) than bellies from pigs fed YGr during the first 3 phases (BT45).

Belly firmness score decreased linearly as DDGS were added to the diet (Widmer et al., 2008; Leick et al., 2010; Xu et al., 2010a,b), and bellies from pigs that were fed 30% DDGS were softer than bellies from pigs fed 0 or 20% DDGS (Whitney et al., 2006). Also, as corn oil increased in the diet from 0 to 4%, belly firmness decreased linearly as measured by the belly flop test (Apple et al., 2011). Softer bellies were most likely a consequence of elevated concentrations of dietary unsaturated fatty acids supplied by DDGS and added oils. On the other hand, belly bending was decreased by the addition of tallow to the diet (Jackson et al., 2009). However, subjective and objective belly firmness was not affected by formulating swine diets with either choice white grease (Weber et al., 2006) or poultry fat (Engel et al., 2001),.

There was no ($P \geq 0.37$) effect of BT inclusion on L*, a*, and visual fat color values of belly fat; however, belly fat from pigs fed YGr during the first 3 feeding phases tended to be more ($P = 0.07$) yellow (greater b* values) than fresh belly fat from pigs fed BT during the first 3 phases (Table 10). In contrast, the color of belly fat from pigs fed BT was lighter (higher L* values) and redder (higher a* values) than belly fat from soybean oil-fed pigs (Apple et al., 2007). However, belly fat color was not affected by including choice white grease, poultry fat (Engel et al., 2001), or increasing inclusion levels of DDGS (Xu et al., 2010b) in swine diets. Moreover, no differences in L*, a*, and b* values were observed in the LM (Xu et al., 2010a, b; Whitney et al., 2006), backfat, or belly fat (Xu et al., 2010a) of pigs fed up to 30% DDGS.

Belly Fatty Acid Composition

Bellies from PC-fed pigs had greater ($P < 0.01$) proportion of total SFA, in particular 16:0 and 18:0 acids, and the minor SFA, including 14:0, 15:0, and 17:0, than bellies from NC-fed pigs (Table 11). Interestingly, belly fat from NC-fed pigs had more ($P < 0.01$) 20:0 than belly fat from PC-fed pigs, and the percentage of 20:0 was greater ($P = 0.05$) in bellies from pigs fed BT during the first 2 feeding phases than pigs fed YGr during the first grower phases. There was a tendency for the proportion of 18:0 to be greater ($P = 0.06$) in bellies from pigs fed BT during the last 2 feeding phases compared to feeding YGr during the last 2 phases (BT123); however, the percentages of all SFA, as well as all individual SFA, was not ($P \geq 0.29$) altered by whether BT was fed in the early or late feeding phases.

Similar to the SFA results, the proportions of all MUFA, 18:1c9, and all minor MUFA – including 14:1, 16:1*t*, 16:1*c*, and 18:1c11 – were greater ($P \leq 0.03$) in bellies from PC-fed than NC-fed pigs (Table 11). Furthermore, the percentages of total MUFA, all minor MUFA, 18:1c9, 18:1c11, 16:1*c*, and 16:1*t* were greater ($P \leq 0.01$) in belly fat from pigs fed BT during the last 3 feeding phases when compared to pigs fed YGr during the last 3 feeding phases. In accordance, the belly fat from pigs fed BT during the late feeding phases contained more ($P \leq 0.01$) MUFA, and specifically 18:1c9, and 16:1*t*, than belly fat from pigs fed BT during the early feeding phases.

On the other hand, bellies from NC-fed pigs had greater ($P < 0.01$) proportions of total PUFA than belly fat from PC-fed pigs (Table 12). More specifically, the weight percentages of 18:2*n*6 and minor PUFA, including α-linolenic acid (18:3*n*3), 20:2, 20:3*n*-6), and 20:4*n*-6, were greater ($P < 0.01$) in bellies from NC-fed than PC-fed pigs. Furthermore, the concentrations of 18:2*n*6, 18:3*n*3, 20:2, and all PUFA were greater ($P < 0.01$) in belly fat from pigs fed BT during the first 2 feeding phases than in pigs fed YGr during the grower phases, and greater ($P < 0.01$) in pigs fed BT during the early than the late feeding phases.

It should be noted, however, that the total CLA content of belly fat was actually greater ($P <$ 0.01) in the fat of PC-fed than NC-fed pigs, as well as in fat from pigs fed YGr during the first 2 feeding phases (BT345) when compared to pigs fed BT during these 2 grower phases (BT12).

Fatty acid results of the present study are in agreement with several published studies where saturated fat sources were fed to growing-finishing pigs (Apple et al., 2007, 2011; Benz et al., 2010). Adding poultry fat (Eggert et al., 1998), choice white grease (Weber et al., 2006), or high-oil corn (Rentfrow et al., 2003) to swine diets decreased total SFA and increased total UFA in fresh belly slices.

Another study found similar results to the present study in which bellies from BT-supplemented pigs were firmer and took more force to compress than those from soybean oil-fed pigs (Apple et al., 2007). Beef tallow-fed pigs had belly fat with the highest percentages of total SFA and elevated levels of total MUFA, including 16:1*t*, 16:1*c*, 17:1*t*, 18:1c9, 18:1c11, and 20:1c11, compared to belly fat from soybean oil-fed pigs. More importantly, feeding diets formulated with soybean oil resulted in a 35% increase in the proportion of PUFA in belly fat; therefore, causing bellies to be considerably softer than those from BT-fed pigs (Apple et al., 2007), which is quite similar to the results of the current study. Soft bellies tend to have low proportions of 16:0 and 18:0 and very high proportions of 18:2*n*-6 (Larsen et al., 2009; Leick et al., 2010), and, based on this criteria, the fatty acid composition of bellies in the present study would be indicative of borderline soft bellies.

As DDGS were increased in swine diet, fresh bellies become softer due to increased PUFA composition (Benz et al., 2010; Leick et al., 2010). In fact, the PUFA content, including 18:2*n*-6, 18:3*n*-3, 20:2, and 20:3*n*-6 increased linearly, while the SFA and MUFA content decreased linearly, with increasing dietary inclusion levels of DDGS (Xu et al.,

2010b). Leick et al. (2010) also noted a shift from 18:1c9 to 18:2*n*-6 in the belly due to increased unsaturation from DDGS. Furthermore, when corn oil was added to swine diets to mimic the inclusion of 20 and 40% DDGS, proportions of 16:0, 18:0, and total SFA, as well as the proportions of all MUFA, decreased linearly, whereas the 18:3*n*-3 and PUFA content increased linearly, with increasing dietary corn oil (Apple et al., 2011).

Iodine values and PUFA:SFA of belly fat were greater ($P < 0.01$) in pigs fed the NC diets compared to the PC diets (Table 12). In addition, IV and PUFA:SFA were greater ($P < 0.01$) in belly fat from pigs fed BT during the first 2 feeding phases than fat from pigs fed YGr during the first 2 phases, and contrasts indicated that belly fat from pigs fed BT during the late feeding phases had lower ($P < 0.01$) IV and PUFA:SFA than that of pigs fed BT during the early feeding phases. An acceptable IV range of 70 to 79 g/100 g of fat has been suggested (Benz et al., 2010), and, in the present study, IV values ranged from 67.85 mg/g for the PC-fed pigs to 72.33 mg/g for the NC-fed pigs, which were within or below this acceptable range.

Bacon Characteristics

Pumped and smoked belly yields of commercially-processed bacon were higher ($P \leq 0.05$) in bellies from pigs fed BT in the early feeding phases than in the late finisher phases (Table 13). However, the percentage of USDA-certified no. 1 slices was not ($P \geq 0.56$) affected by the imposed dietary treatments. Green weight, pumped weight, pressed center weight, or smokehouse yield was not affected by feeding swine diets formulated with choice white grease, high-oil corn, or high-oleic, high-oil corn (Rentfrow et al., 2003). Additionally, Larsen et al. (2009) found that smokehouse and sliced bacon yields were similar among pigs consuming diets formulated with CLA, high-oil corn, or choice white grease.

Similar to fresh belly fat color, L* and b* values for the fat portion of bacon slices was not ($P \geq 0.34$) affected by any dietary treatment; however, there was a tendency for bacon fat from pigs fed BT during the first 3 feeding phases to be redder (greater a* values; $P = 0.07$) than bacon from pigs fed YGr during the first 3 phases (Table 13). Moreover, cooking losses tended to be greater ($P = 0.06$) in bacon from pigs fed YGr during the first 3 phases (BT45) than bacon from pigs fed BT during the first 3 feeding phase. Similarly, Rentfrow et al. (2003) and Jackson et al. (2009) reported no effect of dietary oils, fats, or greases on bacon cooking losses, and bacon cooking yields were not affected by increasing levels of DDGS in swine diets (Leick et al., 2010; Xu et al., 2010b). Lee-Kramer shear force was not ($P \geq 0.73$) affected by phase-feeding fat in the present study, and the available information would indicate that feeding diets with added animal fats has no detrimental effects on shear force values of cooked LM chops (Engel et al., 2001; Jackson et al. (2009).

Sensory attributes of bacon (initial crispiness, bacon flavor intensity, saltiness, sustained chewiness, oiliness, and off flavor intensity) were not ($P \geq 0.55$) affected by the dietary treatments (Table 13). Likewise, bacon from pigs supplemented with choice white grease or poultry fat was similar to controls when evaluated for brittleness, flavor intensity, saltiness, off-flavor, and aftertaste (Engel et al., 2001). In addition, as DDGS inclusion in the diet was increased, trained taste panelists observed a decrease in bacon tenderness, a trend for a decrease in bacon fattiness and rancid taste, and a trend for an increase in bacon crispiness (Widmer et al., 2008). However, Xu et al. (2010b) reported that bacon flavor, off-flavor, crispiness, and overall acceptability were not affected by dietary DDGS, but bacon fattiness and bacon tenderness were linearly reduced with increasing dietary DDGS.

Conclusions

The results of the current study indicate that phase-feeding BT in place of YGr to pigs fed diets formulated with up to 30% DDGS had little to no impact on live pig performance and carcass characteristics. Furthermore, subcutaneous fat depots in pigs fed BT for the entirety of the trial had greater SFA and MUFA composition and lower PUFA compared to fat in pigs fed YGr throughout the trial. Additionally, the fatty acid composition of backfat and jowl fat from pigs fed BT in the finisher phases was more similar to backfat and jowl fat from pigs fed BT the entire trial, especially when compared to feeding YGr in the later feeding phases. Even though belly fatty acid composition from pigs fed BT in the late finisher phases was more similar to fat from pigs fed BT across the entire trial, phase-feeding BT had no appreciable effects on yields or quality characteristics of commercially-processed bacon.

Table 1. Beef tallow (gray area) and yellow grease (clear area) inclusion rates in experimental swine diets[1,2]

Production Phase	Grower-I (23 to 41 kg)	Grower-II (41 to 59 kg)	Finisher-I (59 to 82 kg)	Finisher-II (82 to 104 kg)	Finisher-III (104 to 125 kg)
Negative control	4.7%	4.7%	4.7%	4.7%	4.7%
Positive control	5.0%	5.0%	5.0%	5.0%	5.0%
BT12	5.0%	5%	4.7%	4.7%	4.7%
BT123	5%	5%	5%	4.7%	4.7%
BT345	4.7%	4.7%	5%	5%	5%
BT45	4.7%	4.7%	4.7%	5%	5%

[1] All diets within a feeding phase were isocaloric and isolysinic.
[2] Grower-I, Grower-II, and Finisher-I diets contained 30% DDGS; Finisher-II diets contained 15% DDGS; and Finisher-II diets contained no DDGS.

Table 2. Composition[1] of grower I, grower II, finisher I, finisher II, and finisher III diets

Item	Grower I (26.5 to 42.7 kg)	Grower II (42.7 to 61.6 kg)	Finisher I (61.6 to 81.1 kg)	Finisher II (81.1 to 101.0 kg)	Finisher III (101.0 to 124.1 kg)
Ingredient, %					
Corn	38.41	44.45	49.29	64.95	78.92
Soybean meal	23.55	17.95	13.20	12.55	13.50
DDGS	30.00	30.00	30.00	15.00	0.00
Sand[2]	0.32	0.32	0.32	0.32	0.32
Yellow grease[2]	4.68	4.68	4.68	4.68	4.68
Beef tallow[2]	0.00	0.00	0.00	0.00	0.00
Dicalcium phosphate	0.74	0.44	0.35	0.72	0.96
Limestone	1.20	1.10	1.13	0.88	0.69
Salt	0.40	0.40	0.40	0.40	0.40
L-Lysine	0.30	0.27	0.25	0.21	0.20
L-Threonine	0.02	0.01	0.00	0.01	0.05
Vitamin premix[3]	0.15	0.15	0.15	0.10	0.10
Mineral premix[4]	0.15	0.15	0.15	0.12	0.12
Ethoxiquin	0.03	0.03	0.03	0.03	0.03
Tylan-40	0.05	0.05	0.05	0.02	0.02
Calculated composition, %					
CP	22.56	20.37	18.49	15.51	13.19
Total Lysine	1.31	1.14	0.99	0.85	0.77
TID[5] Lysine	1.12	0.96	0.82	0.72	0.68
TID M+C[6]	0.66	0.61	0.56	0.48	0.42
TID Threonine	0.68	0.60	0.53	0.47	0.46
TID Tryptophan	0.20	0.17	0.14	0.13	0.12
Total P	0.64	0.56	0.52	0.52	0.49
Available P	0.36	0.30	0.28	0.26	0.22
Ca	0.75	0.63	0.61	0.58	0.56
ME, Mcal/kg	3.53	3.55	3.55	3.55	3.55

[1]Ingredients and diet composition reported on an as-fed basis.

[2]Beef tallow (5%) replaced yellow grease (4.68%) and sand (0.32%) resulting in an isocaloric diet within each phase.

[3]Premix supplied 6,614 IU of vitamin A, 827 IU of vitamin D_3, 26 IU of vitamin E, 2.7 mg of vitamin K, 16.5 mg of pantothenic acid, 30 mg of niacin, 5 mg of riboflavin, and 26 µg of vitamin B_{12} per kilogram of feed (Nutra Blend Corp., Neosho, MO).

[4]Premix supplied 138 mg/kg of Fe from ferrous sulfate, 138 mg/kg of Zn from zinc sulfate, 33 mg/kg of Mn as manganous sulfate, 13.8 mg/kg of Cu from copper sulfate, 0.25 mg/kg of Se from sodium selenite, and 0.25 mg/kg of I from calcium iodate per kilogram of feed (Nutra Blend Corp., Neosho, MO).

[5]TID = total ileal digestible.

[6]M+C = methionine plus cysteine.

Table 3. Fatty acid composition[1] of dietary fat sources

Fatty acid composition, %	Dietary fat source	
	Beef tallow[2]	Yellow grease[3]
SFA	46.48	33.45
Myristic acid (14:0)	2.70	2.10
Pentadecanoic acid (15:0)	0.50	0.30
Palmitic acid (16:0)	22.70	19.00
Margaric acid (17:0)	1.40	1.00
Stearic acid (18:0)	18.96	10.72
Arachidic acid (20:0)	0.14	0.21
MUFA[4]	45.74	45.07
Myristoleic acid (14:1)	0.48	0.50
Palmitelaidic acid (16:1*t*)	0.42	0.25
Palmitoleic acid (16:1*c*)	2.35	2.30
Heptadecenoic acid (17:1*t*)	0.14	0.09
Total 18:1*t* fatty acids	5.35	4.83
Oleic acid (18:1*c*9)	35.21	34.63
Vaccenic acid (18:1*c*11)	1.58	2.06
Gadoleic acid (20:1*c*11)	0.21	0.41
PUFA	3.40	16.79
Linoleic acid (18:2n-6)	2.55	14.92
CLA (18:2*c*9*t*11)	0.50	0.27
α-Linolenic acid (18:3n-3)	0.21	1.29
γ-Linolenic acid (18:3n-6)	ND[7]	0.13
Eicosadienoic acid (20:2)	0.03	0.08
Dihomo-γ-linolenic acid (20:3n-6)	0.06	0.05
Arachidonic acid (20:4n-6)	0.03	0.04
Docosapentaenoic acid (22:5n-3)	0.01	0.01
Other fatty acid peaks	4.23	4.37
PUFA:SFA [5]	0.07	0.50
Iodine value,[6] mg/g	44.88	68.46

[1]As-fed basis.
[2]Values represent averages of 12 beef tallow samples.
[3]Values represent averages of 11 yellow grease samples.
[4]*t* = *trans*; *c* = *cis*.
[5]The PUFA:SFA ratio is calculated as: [Total PUFA] / [Total SFA], where brackets indicate concentrations.
[6]Iodine value = (0.95 × [∑ 16:1]) + (0.86 × [∑ 18:1]) + (1.732 × [∑ 18:2]) + (2.616 × [∑ 18:3]) + (0.785 × [20:1c11]), where brackets indicate concentrations (AOCS, 1998).
[7]ND = not detectable

Table 4. Fatty acid composition (as-fed basis) of grower and finisher diets

	Diet phase with yellow grease as fat source[1]					Diet phase with beef tallow as fat source[1]				
Fatty acid composition, %	1	2	3	4	5	1	2	3	4	5
SFA	24.67	24.28	24.36	27.29	26.71	32.03	31.51	32.86	34.63	34.68
Myristic acid (14:0)	1.04	1.00	0.99	1.25	1.15	1.51	1.47	1.55	1.68	1.59
Pentadecanoic acid (15:0)	0.17	0.17	0.17	0.22	0.21	0.26	0.26	0.26	0.29	0.29
Palmitic acid (16:0)	16.07	15.92	15.84	16.90	16.41	18.06	17.86	18.21	18.65	18.39
Margaric acid (17:0)	0.50	0.48	0.49	0.62	0.59	0.78	0.78	0.82	0.91	0.89
Stearic acid (18:0)	6.55	6.37	6.53	7.96	7.98	11.15	10.87	11.74	12.81	13.21
Arachidic acid (20:0)	0.33	0.34	0.34	0.34	0.37	0.27	0.27	0.28	0.29	0.31
MUFA[2]	34.34	33.58	33.93	35.74	37.45	35.42	35.56	35.51	36.68	37.51
Myristoleic acid (14:1)	0.22	0.21	0.20	0.26	0.24	0.27	0.27	0.26	0.28	0.26
Palmitoleic acid (16:1*c*)	1.11	1.04	1.02	1.24	1.21	1.27	1.28	1.25	1.36	1.27
Heptadecenoic acid (17:1*t*)	ND[5]	ND	ND	ND	ND	0.06	0.07	0.07	0.08	ND
Total 18:1*t* fatty acids	2.26	2.11	2.13	2.70	2.64	2.75	2.72	2.82	3.13	3.02
Oleic acid (18:1*c*9)	28.84	28.37	28.82	29.70	31.52	29.33	29.46	29.46	30.21	31.38
Vaccenic acid (18:1*c*11)	1.60	1.54	1.46	1.51	1.49	1.52	1.54	1.43	1.39	1.34
Gadoleic acid (20:1*c*11)	0.31	0.31	0.30	0.33	0.35	0.22	0.22	0.22	0.23	0.24
PUFA	38.33	39.65	39.33	34.10	33.46	29.76	30.18	28.85	25.69	25.09
Linoleic acid (18:2n-6)	36.44	37.87	37.68	32.42	31.69	28.32	28.84	27.63	24.46	23.88
CLA (18:2*c*9*t*11)	0.12	0.11	0.11	0.14	0.13	0.26	0.25	0.26	0.29	0.27
α-Linolenic acid (18:3n-3)	1.72	1.64	1.50	1.47	1.45	1.16	1.09	0.95	0.90	0.88
Eicosadienoic acid (20:2)	0.06	0.03	0.03	0.07	0.18	0.03	ND	ND	0.05	0.06
Other fatty acid peaks	2.47	2.30	2.18	2.65	2.38	2.69	2.67	2.66	2.90	2.64
PUFA:SFA[3]	0.93	0.96	0.88	0.74	0.72	0.96	0.99	0.91	0.77	0.75
Iodine value, mg/g[4]	97.23	98.84	98.46	90.84	91.00	82.80	83.62	81.16	76.54	76.26

[1]1 = grower-I; 2 = grower-II, 3 = finisher-I; 4 = finisher-II; and 5 = finisher-III.

[2]*t=trans; c=cis*.

[3]The PUFA:SFA ratio was calculated as: [Total PUFA] / [Total SFA], where brackets indicate concentrations.

[4]Iodine value = (0.95 × [∑ 16:1]) + (0.86 × [∑ 18:1]) + (1.732 × [∑ 18:2]) + (2.616 × [∑ 18:3]) + (0.785 × [20:1c11]), where brackets indicate concentrations (AOCS, 1998).

[5]ND = not detectable.

Table 5. Effect of dietary treatments on growth performance of growing-finishing swine

Item	Dietary Treatment [1]						SEM	*P*-value	Contrasts[2]
	NC	BT12	BT123	BT345	BT45	PC			
No. of pens	6	6	6	6	6	6			
Grower-I phase (26.5 to 42.7 kg)									
ADG, kg	1.88	1.86	1.84	1.84	1.90	1.89	0.065	0.90	
ADFI,[3] kg	3.48	3.57	3.49	3.56	3.43	3.53	0.103	0.67	
G:F[3]	0.54	0.52	0.53	0.52	0.55	0.53	0.010	0.15	
Grower-II phase (42.7 to 61.6 kg)									
ADG, kg	2.34	2.38	2.31	2.30	2.27	2.28	0.041	0.44	
ADFI,[3] kg	5.31	5.40	5.23	5.33	5.16	5.22	0.122	0.59	
G:F[3]	0.44	0.44	0.44	0.43	0.44	0.44	0.009	0.95	
Finisher-I phase (61.6 to 81.1 kg)									
ADG, kg	2.27	2.24	2.30	2.32	2.20	2.31	0.051	0.54	
ADFI,[3] kg	6.12	6.17	6.10	6.11	5.84	6.02	0.136	0.56	
G:F[3]	0.37	0.37	0.38	0.38	0.38	0.38	0.009	0.74	
Finisher-II phase (81.1 to 101.0 kg)									
ADG, kg	2.24	2.16	2.12	2.16	2.30	2.10	0.062	0.19	C
ADFI,[3] kg	6.09^{abc}	6.29^{a}	5.97^{bc}	6.07^{abc}	6.22^{ab}	5.80^{c}	0.121	0.04	
G:F[3]	0.37	0.34	0.35	0.36	0.37	0.36	0.007	0.18	
Finisher-III phase (101.0 to 124.1 kg)									
ADG, kg	1.73	1.93	1.98	2.00	1.83	1.84	0.081	0.14	
ADFI,[3] kg	6.04	6.34	6.32	6.33	6.08	5.82	0.165	0.12	
G:F[3]	0.29	0.30	0.31	0.32	0.30	0.32	0.008	0.11	A
Overall (26.5 to 124.1 kg)									
ADG, kg	2.04^{yz}	2.10^{xy}	2.05^{yz}	2.11^{x}	2.03^{z}	2.06^{xyz}	0.026	0.10	
ADFI,[3] kg	5.45^{xy}	5.62^{x}	5.46^{xy}	5.54^{xy}	5.39^{y}	5.32^{z}	0.083	0.09	
G:F[3]	0.37	0.37	0.37	0.38	0.38	0.39	0.005	0.25	

$^{a-c}$ Within a row, least squares means lacking a common superscript letter differ ($P < 0.05$).

^{x,z} Within a row, lease squares means lacking a common superscript letter differ ($P < 0.10$).

[1]NC = grower and finisher diets formulated with 4.7% yellow grease (YGr) fed during all 5 feeding phases; BT12 = diets formulated with 5.0% beef tallow (BT) during the first 2 feeding phases and diets containing 4.7% YGr fed during the last 3

phases; BT123 = diets formulated with 5.0% BT fed during the first 3 phases and diets containing 4.7% YGr fed during the last 2 phases; BT345 = diets containing 4.7% YGr fed during the first 2 feeding phases and diets with 5.0% BT fed during the last 3 phases; BT45 = diets with 4.7% YGr fed during the first 3 phases and diets with 5.0% BT fed during the last 2 phases; and PC = diets formulated with 5.0% BT fed during all 5 feeding phases.

[2]Significant ($P \leq 0.05$) orthogonal contrasts for: A = NC vs. PC diets; B = BT vs. YGr fed in the first 2 phases; C = BT vs. YGr fed in the first 3 phases; and D = BT fed in the early feeding phases vs. BT fed in the late feeding phases.

[3]As-fed basis.

Table 6. Effect of dietary treatments on carcass characteristics

	Dietary treatment [1]								
Item	NC	BT12	BT123	BT345	BT45	PC	SEM	*P*-value	Contrasts[2]
No. of pens	6	6	6	6	6	6			
Slaughter weight, kg	123.30	124.68	124.90	126.25	124.40	123.24	1.586	0.49	
Dressing percentage, %	73.54	73.64	73.06	73.48	73.60	74.03	0.315	0.45	
HCW, kg	90.62	91.84	91.24	92.67	91.55	91.20	1.229	0.75	
Lean/muscle yield, %	51.90	50.91	51.25	51.54	51.14	51.61	0.320	0.23	
LM depth, cm	5.63	5.42	5.53	5.70	5.60	5.66	1.035	0.29	B
10th rib fat depth, cm	2.02	2.17	2.14	2.20	2.21	2.10	0.735	0.46	

[1]NC = grower and finisher diets formulated with 4.7% yellow grease (YGr) fed during all 5 feeding phases; BT12 = diets formulated with 5.0% beef tallow (BT) during the first 2 feeding phases and diets containing 4.7% YGr fed during the last 3 phases; BT123 = diets formulated with 5.0% BT fed during the first 3 phases and diets containing 4.7% YGr fed during the last 2 phases; BT345 = diets containing 4.7% YGr fed during the first 2 feeding phases and diets with 5.0% BT fed during the last 3 phases; BT45 = diets with 4.7% YGr fed during the first 3 phases and diets with 5.0% BT fed during the last 2 phases; and PC = diets formulated with 5.0% BT fed during all 5 feeding phases.
[2]Significant ($P \leq 0.05$) orthogonal contrasts for: A = NC vs. PC diets; B = BT vs. YGr fed in the first 2 phases; C = BT vs. YGr fed in the first 3 phases; and D = BT fed in the early feeding phases vs. BT fed in the late feeding phases.

Table 7. Effect of phase-feeding dietary fats on the SFA composition of backfat and jowl fat samples

Fatty acid composition, %	Dietary treatments[1] NC	BT12	BT123	BT345	BT45	PC	SEM	*P*-value	Contrasts[2]
Last lumbar vertebrae									
Total SFA	32.60^{c}	33.53^{b}	33.36^{bc}	33.69^{b}	34.58^{a}	34.11^{a}	0.361	<0.01	A, C, D
Palmitic acid (16:0)	20.01^{c}	20.56^{ab}	20.44^{b}	20.71^{ab}	20.94^{a}	20.78^{ab}	0.192	<0.01	A, C, D
Stearic acid (18:0)	10.19^{c}	10.44^{bc}	10.36^{bc}	10.37^{bc}	11.09^{a}	10.67^{ab}	0.211	0.04	C
Minor SFA	2.41^{c}	2.54^{b}	2.56^{b}	2.61^{ab}	2.56^{b}	2.67^{a}	0.028	<0.01	A
Myristic acid (14:0)	1.32^{b}	1.41^{a}	1.42^{a}	1.46^{a}	1.42^{a}	1.46^{a}	0.021	<0.01	A
Pentadecanoic acid (15:0)	0.11^{c}	0.12^{bc}	0.13^{b}	0.13^{ab}	0.12^{bc}	0.14^{a}	0.003	<0.01	A
Margaric acid (17:0)	0.61^{c}	0.64^{bc}	0.67^{b}	0.67^{b}	0.66^{b}	0.72^{a}	0.013	<0.01	A
Arachidic acid (20:0)	0.19^{a}	0.18^{a}	0.17^{bc}	0.17^{c}	0.18^{ab}	0.17^{bc}	0.004	<0.01	A, B
Jowl									
Total SFA	29.59	30.67	30.33	30.49	30.66	30.77	0.324	0.15	A
Palmitic acid (16:0)	19.41	19.90	19.88	20.03	20.19	20.07	0.199	0.14	A
Stearic acid (18:0)	7.94	8.37	8.01	8.03	8.10	8.20	0.159	0.45	
Minor SFA	2.24^{c}	2.40^{ab}	2.45^{ab}	2.43^{ab}	2.38^{b}	2.50^{a}	0.036	<0.01	A
Myristic acid (14:0)	1.33^{b}	1.41^{a}	1.45^{a}	1.45^{a}	1.44^{a}	1.47^{a}	0.029	0.01	A
Pentadecanoic acid (15:0)	0.09^{c}	0.11^{ab}	0.11^{a}	0.10^{ab}	0.10^{bc}	0.11^{a}	0.003	<0.01	A, C, D
Margaric acid (17:0)	0.46^{c}	0.53^{ab}	0.53^{ab}	0.52^{b}	0.48^{c}	0.56^{a}	0.011	<0.01	A, C, D
Arachidic acid (20:0)	0.16^{a}	0.16^{ab}	0.15^{b}	0.15^{b}	0.15^{ab}	0.15^{b}	0.004	0.05	A

^{a} - ^{c}Within a row, least squares means lacking a common superscript letter differ ($P < 0.05$).

[1]NC = diets formulated with 4.7% yellow grease (YGr) and fed during all phases; PC = diets formulated with 5.0% beef tallow (BT) and fed during all phases; BT12 = diets with 5.0% BT fed during the first 2 feeding phases and diets with 4.7% YGr fed the remaining 3 phases; BT123 = diets with 5.0% BT fed during the first 3 phases and diets with 4.7% YGr fed the remaining 2 phases; BT345 = diets with 4.7% YGr fed during the first 2 feeding phases followed by the 5.0% BT formulated diets the last 3 phases; and BT45 = diets formulated with 4.7% YGr fed during the first 3 phases and diets with 5.0% BT fed during the last 3 feeding phases.

[2]Significant ($P \leq 0.05$) orthogonal contrasts for: A = NC vs. PC diets; B = BT vs. YGr fed in the first 2 phases; C = BT vs. YGr fed in the first 3 phases; and D = BT fed in the early feeding phases vs. BT fed in the late feeding phases.

Table 8. Effect of phase-feeding dietary fats on the MUFA composition of backfat and jowl fat samples

	Dietary treatment[1]								
Fatty acid composition, %	NC	BT12	BT123	BT345	BT45	PC	SEM	*P*-value	Contrasts[2]
Last lumbar vertebrae									
Total MUFA[3]	42.60^{e}	43.36^{de}	43.88^{cd}	45.19^{a}	44.21^{bc}	45.05^{ab}	0.295	<0.01	A, B, D
Oleic acid (18:1c9)	35.42^{d}	36.09^{c}	36.49^{bc}	37.47^{a}	36.79^{ab}	37.29^{a}	0.223	<0.01	A, B, D
Minor MUFA	7.18^{b}	7.27^{b}	7.39^{b}	7.72^{a}	7.43^{b}	7.76^{a}	0.097	<0.01	A, B, D
Myristoleic acid (14:1)	0.05^{b}	0.05^{b}	0.05^{b}	0.06^{a}	0.06^{b}	0.06^{a}	0.001	<0.01	A, B, D
Palmitelaidic acid (16:1*t*)	0.14^{d}	0.15^{d}	0.16^{c}	0.19^{b}	0.17^{c}	0.20^{a}	0.003	<0.01	A, B, D
Palmitoleic acid (16:1*c*)	1.81^{b}	1.88^{b}	1.91^{ab}	2.03^{a}	1.86^{b}	2.01^{a}	0.043	0.01	A, B
Heptadecenoic acid (17:1*t*)	0.05^{f}	0.06^{e}	0.06^{d}	0.07^{b}	0.06^{c}	0.07^{a}	0.001	<0.01	A, B, C, D
Total 18:1*t* fatty acids	1.55^{b}	1.51^{b}	1.55^{b}	1.57^{ab}	1.56^{b}	1.63^{a}	0.022	0.02	A
Vaccenic acid (18:1c11)	2.83	2.87	2.91	3.06	2.94	3.05	0.062	0.08	A, B
Gadoleic acid (20:1c11)	0.74	0.75	0.74	0.75	0.78	0.74	0.013	0.27	
Jowl									
Total MUFA[3]	46.86^{c}	47.01^{bc}	47.91^{a}	47.81^{ab}	47.69^{ab}	48.50^{a}	0.290	0.01	A
Oleic acid (18:1c9)	38.36^{b}	38.50^{b}	39.03^{ab}	38.71^{b}	38.74^{b}	39.53^{a}	0.245	0.03	A
Minor MUFA	8.50^{b}	8.51^{b}	8.88^{a}	9.10^{a}	8.95^{a}	8.98^{a}	0.116	<0.01	A, B, D
Myristoleic acid (14:1)	0.05^{c}	0.05^{bc}	0.06^{ab}	0.06^{ab}	0.05^{abc}	0.06^{a}	0.002	0.01	A
Palmitelaidic acid (16:1*t*)	0.12^{e}	0.14^{c}	0.15^{b}	0.15^{bc}	0.13^{d}	0.17^{a}	0.003	<0.01	A, C, D
Palmitoleic acid (16:1*c*)	2.56^{b}	2.58^{b}	2.76^{ab}	2.84^{a}	2.80^{a}	2.78^{a}	0.075	0.04	A, B, D
Heptadecenoic acid (17:1*t*)	0.04^{d}	0.05^{b}	0.05^{b}	0.05^{b}	0.05^{c}	0.06^{a}	0.001	<0.01	A, C, D
Total 18:1*t* fatty acids	1.21^{b}	1.27^{a}	1.26^{a}	1.26^{ab}	1.20^{b}	1.30^{a}	0.021	0.02	A, C
Vaccenic acid (18:1c11)	3.71^{bc}	3.64^{c}	3.84^{ab}	3.97^{a}	3.93^{a}	3.83^{ab}	0.065	0.01	B, D
Gadoleic acid (20:1c11)	0.81	0.79	0.76	0.77	0.79	0.78	0.015	0.32	

$^{a-e}$ Within a row, least squares means lacking a common superscript letter differ ($P \leq 0.05$).

[1]NC = grower and finisher diets formulated with 4.7% yellow grease (YGr) fed during all 5 feeding phases; BT12 = diets formulated with 5.0% beef tallow (BT) during the first 2 feeding phases and diets containing 4.7% YGr fed during the last 3 phases; BT123 = diets formulated with 5.0% BT fed during the first 3 phases and diets containing 4.7% YGr fed during the last 2 phases; BT345 = diets containing 4.7% YGr fed during the first 2 feeding phases and diets with 5.0% BT fed during the last 3 phases; BT45 = diets with 4.7% YGr fed during the first 3 phases and diets with 5.0% BT fed during the last 2 phases; and PC = diets formulated with 5.0% BT fed during all 5 feeding phases.

[2]Significant ($P \leq 0.05$) orthogonal contrasts for: A = NC vs. PC diets; B = BT vs. YGr fed in the first 2 phases; C = BT vs. YGr fed in the first 3 phases; and D = BT fed in the early feeding phases vs. BT fed in the late feeding phases.

[3]*t* = *trans*; *c* = *cis*.

Table 9. Effect of phase-feeding dietary fats on the PUFA composition of backfat and jowl fat samples

Fatty acid composition, %	Dietary treatment[1]						SEM	*P*-value	Contrasts[2]
	NC	BT12	BT123	BT345	BT45	PC			
Last lumbar vertebrae									
Total PUFA	22.30[a]	20.65[b]	20.27[b]	18.59[c]	18.76[c]	18.27[c]	0.407	<0.01	A, B, C, D
Linoleic acid (18:2*n*-6)	19.67[a]	18.19[b]	17.82[b]	16.27[c]	16.43[c]	15.98[c]	0.371	<0.01	A, B, C, D
Minor PUFA	1.72	1.64	1.67	1.65	1.63	1.64	0.024	0.07	A
Total CLA[3]	0.35[e]	0.38[d]	0.41[c]	0.48[a]	0.43[b]	0.49[a]	0.007	<0.01	A, B, C, D
CLA (18:2*c*9*t*11)	0.29[e]	0.32[d]	0.35[c]	0.42[a]	0.38[b]	0.44[a]	0.006	<0.01	A, B, C, D
CLA (18:2*c*9*c*11)	0.06[a]	0.05[b]	0.05[bc]	0.05[d]	0.05[cd]	0.05[d]	0.001	<0.01	A, B, D
CLA (18:2*t*9*t*11)	0.01	0.01	0.01	0.01	0.01	0.01	0.003	0.53	
α-Linolenic acid (18:3*n*-3)	0.91[a]	0.84[b]	0.78[c]	0.67[de]	0.70[d]	0.64[e]	0.017	<0.01	
γ-Linolenic acid (18:3*n*-6)	0.03	0.02	0.03	0.03	0.02	0.03	0.003	0.17	A, B, C, D
Eicosadienoic acid (20:2)	0.74[a]	0.69[b]	0.68[b]	0.62[c]	0.65[d]	0.61[d]	0.011	<0.01	B
Dihomo-γ-linolenic acid (20:3*n*-6)	0.13[a]	0.12[b]	0.12[b]	0.12[b]	0.12[b]	0.12[b]	0.003	0.03	A, B, C, D
Arachidonic acid (20:4*n*-6)	0.28[a]	0.26[b]	0.26[ab]	0.25[b]	0.24[b]	0.25[b]	0.007	0.05	A
Jowl									
Total PUFA	21.44[a]	20.09[b]	19.50[b]	19.47[b]	19.54[b]	18.40[c]	0.346	<0.01	A
Linoleic acid (18:2*n*-6)	18.70[a]	17.52[b]	16.97[b]	16.93[b]	16.99[b]	15.94[c]	0.307	<0.01	A
Minor PUFA	1.87	1.78	1.79	1.79	1.78	1.79	0.034	0.42	
Total CLA[3]	0.36[d]	0.41[c]	0.45[b]	0.45[b]	0.41[c]	0.50[a]	0.007	<0.01	A, B, C
CLA (18:2*c*9*t*11)	0.29[d]	0.34[c]	0.38[b]	0.37[b]	0.33[c]	0.42[a]	0.005	<0.01	A, B, C
CLA (18:2*c*9*c*11)	0.05[a]	0.05[bc]	0.05[c]	0.05[ab]	0.05[bc]	0.05[c]	0.001	<0.01	A
CLA (18:2*t*9*t*11)	0.03	0.03	0.03	0.04	0.04	0.04	0.003	0.14	D
α-Linolenic acid (18:3*n*-3)	0.87[a]	0.79[b]	0.74[c]	0.75[c]	0.77[bc]	0.67[d]	0.013	<0.01	A, B
γ-Linolenic acid (18:3*n*-6)	0.03	0.03	0.04	0.03	0.03	0.04	0.003	0.22	C
Eicosadienoic acid (20:2)	0.81[a]	0.73[b]	0.70[bc]	0.70[bc]	0.73[b]	0.67[c]	0.017	<0.01	A
Dihomo-γ-linolenic acid (20:3*n*-6)	0.14	0.13	0.13	0.13	0.13	0.13	0.004	0.17	A
Arachidonic acid (20:4*n*-6)	0.29	0.28	0.29	0.28	0.28	0.27	0.008	0.46	

[a,b,c,d,e] Within a row, least squares means lacking a common superscript letter differ ($P \leq 0.05$).
[1]NC = grower and finisher diets formulated with 4.7% yellow grease (YGr) fed during all 5 feeding phases; BT12 = diets formulated with 5.0% beef tallow (BT) during the first 2 feeding phases and diets containing 4.7% YGr fed during the last 3 phases; BT123 = diets formulated with 5.0% BT fed during the first 3 phases and diets containing 4.7% YGr fed during the last 2 phases; BT345 = diets containing 4.7% YGr fed during the first 2 feeding phases and diets with 5.0% BT fed during the last 3 phases; BT45 = diets with 4.7% YGr fed during the first 3 phases and diets with 5.0% BT fed during the last 2 phases; and PC = diets formulated with 5.0% BT fed during all 5 feeding phases.
[2]Significant ($P \leq 0.05$) orthogonal contrasts for: A = NC vs. PC diets; B = BT vs. YGr fed in the first 2 phases; C = BT vs. YGr fed in the first 3 phases; and D = BT fed in the early feeding phases vs. BT fed in the late feeding phases.
[3]*t = trans; c = cis.*

Table 10. Effect of dietary treatments on fresh belly characteristics

Item	Dietary treatment [1]						SEM	*P*-value	Contrasts[2]
	NC	BT12	BT123	BT345	BT45	PC			
Width, cm	33.51	34.14	33.71	33.81	34.19	33.38	0.427	0.71	
Length, cm	66.73	66.81	68.58	68.29	67.59	67.65	0.558	0.15	
Thickness, cm	2.70	2.90	2.85	2.87	2.86	2.90	0.096	0.67	
Fat color									
Lightness (L*)[3]	81.72	81.07	81.60	81.65	81.03	82.20	0.524	0.63	
Redness (a*)[3]	10.42	10.90	10.50	10.12	11.37	10.19	0.445	0.37	
Yellowness (b*)[3]	13.69^{y}	14.02^{xy}	13.78^{y}	13.10^{y}	14.86^{x}	13.41^{y}	0.397	0.08	
Visual	2.51	2.49	2.35	2.34	2.46	2.29	0.159	0.86	
Belly flop, cm									
Skin-side up	14.54^{y}	16.74^{xy}	16.20^{xy}	18.45^{x}	17.40^{x}	17.11^{x}	0.921	0.09	A
Skin-side down	12.17^{y}	15.16^{x}	14.53^{x}	15.06^{x}	15.68^{x}	14.78^{x}	0.843	0.07	A
Belly angle, °									
Skin-side up	25.24^{y}	28.95^{xy}	27.30^{xy}	31.35^{x}	30.01^{x}	29.47^{x}	1.561	0.09	A
Skin-side down	21.05^{y}	26.16^{x}	24.39^{xy}	25.51^{x}	26.82^{x}	25.33^{x}	1.386	0.06	A
Puncture force, kg	7.75	8.51	9.43	8.25	7.30	7.42	0.756	0.38	

$^{x\text{-}z}$ Within a row, lease squares means lacking a common superscript letter differ ($P < 0.10$).

[1]NC = grower and finisher diets formulated with 4.7% yellow grease (YGr) fed during all 5 feeding phases; BT12 = diets formulated with 5.0% beef tallow (BT) during the first 2 feeding phases and diets containing 4.7% YGr fed during the last 3 phases; BT123 = diets formulated with 5.0% BT fed during the first 3 phases and diets containing 4.7% YGr fed during the last 2 phases; BT345 = diets containing 4.7% YGr fed during the first 2 feeding phases and diets with 5.0% BT fed during the last 3 phases; BT45 = diets with 4.7% YGr fed during the first 3 phases and diets with 5.0% BT fed during the last 2 phases; and PC = diets formulated with 5.0% BT fed during all 5 feeding phases.

[2]Significant ($P \leq 0.05$) orthogonal contrasts for: A = NC vs. PC diets; B = BT vs. YGr fed in the first 2 phases; C = BT vs. YGr fed in the first 3 phases; and D = BT fed in the early feeding phases vs. BT fed in the late feeding phases

[3]L* = a measure of darkness to lightness (greater L* values indicate a lighter color); a* = a measure of redness (greater a* values indicate a redder color); and b* = a measure of yellowness (greater b* value indicates a more yellow color).

Table 11. Effect of phase-feeding dietary fats on the SFA and MUFA composition of belly fat samples

Fatty acid composition, %	Dietary treatment [1]						SEM	*P*-value	Contrasts[2]
	NC	BT12	BT123	BT345	BT45	PC			
Total SFA	32.27^{c}	33.29^{b}	33.09^{b}	33.30^{b}	33.52^{ab}	34.03^{a}	0.267	<0.01	A
Palmitic acid (16:0)	20.57^{b}	21.15^{a}	21.10^{a}	21.34^{a}	21.22^{a}	21.44^{a}	0.165	<0.01	A
Stearic acid (18:0)	9.28^{c}	9.55^{abc}	9.39^{bc}	9.33^{c}	9.75^{ab}	9.89^{a}	0.129	0.01	A
Minor SFA	2.42^{d}	2.59^{bc}	2.59^{bc}	2.64^{ab}	2.55^{c}	2.70^{a}	0.030	<0.01	A
Myristic acid (14:0)	1.41^{c}	1.54^{ab}	1.53^{ab}	1.58^{a}	1.50^{b}	1.57^{a}	0.024	<0.01	A
Pentadecanoic acid (15:0)	0.10^{c}	0.11^{bc}	0.11^{ab}	0.11^{b}	0.11^{bc}	0.12^{a}	0.003	<0.01	A
Margaric acid (17:0)	0.55^{c}	0.56^{b}	0.58^{b}	0.57^{b}	0.57^{b}	0.63^{a}	0.013	<0.01	A
Arachidic acid (20:0)	0.17^{a}	0.17^{ab}	0.16^{c}	0.16^{c}	0.16^{bc}	0.16^{bc}	0.004	0.01	A, B
Total MUFA[3]	44.94^{d}	45.27^{cd}	46.20^{ab}	47.10^{a}	46.11^{bc}	46.56^{ab}	0.322	<0.01	A, B, D
Oleic acid (18:1*c*9)	37.14^{c}	37.31^{bc}	37.91^{ab}	38.54^{a}	38.00^{ab}	38.0^{a}	0.243	<0.01	A, B, D
Minor MUFA	7.81^{c}	7.96^{bc}	8.29^{ab}	8.56^{a}	8.11^{bc}	8.27^{ab}	0.113	<0.01	A, B
Myristoleic acid (14:1)	0.05^{c}	0.06^{bc}	0.06^{b}	0.06^{a}	0.06^{b}	0.06^{a}	0.001	<0.01	A, B
Palmitelaidic acid (16:1*t*)	0.13^{e}	0.14^{d}	0.15^{c}	0.17^{b}	0.15^{c}	0.18^{a}	0.003	<0.01	A, B, D
Palmitoleic acid (16:1*c*)	2.30^{c}	2.40^{bc}	2.48^{ab}	2.61^{a}	2.38^{bc}	2.52^{ab}	0.051	<0.01	A, B
Heptadecenoic acid (17:1*t*)	0.05^{e}	0.05^{d}	0.05^{c}	0.06^{b}	0.06^{b}	0.07^{a}	0.001	<0.01	A, B, D
Total 18:1*t* fatty acids	1.37^{b}	1.36^{b}	1.37^{b}	1.39^{b}	1.39^{ab}	1.45^{a}	0.021	0.06	A
Vaccenic acid (18:1*c*11)	3.20^{c}	3.27^{bc}	3.48^{ab}	3.58^{a}	3.37^{abc}	3.31^{bc}	0.081	0.03	B
Gadoleic acid (20:1*c*11)	0.71	0.69	0.69	0.70	0.70	0.68	0.011	0.56	

[a,b,c,d,e,f] Within a row, least squares means lacking a common superscript letter differ ($P \leq 0.05$).

[1]NC = grower and finisher diets formulated with 4.7% yellow grease (YGr) fed during all 5 feeding phases; BT12 = diets formulated with 5.0% beef tallow (BT) during the first 2 feeding phases and diets containing 4.7% YGr fed during the last 3 phases; BT123 = diets formulated with 5.0% BT fed during the first 3 phases and diets containing 4.7% YGr fed during the last 2 phases; BT345 = diets containing 4.7% YGr fed during the first 2 feeding phases and diets with 5.0% BT fed during the last 3 phases; BT45 = diets with 4.7% YGr fed during the first 3 phases and diets with 5.0% BT fed during the last 2 phases; and PC = diets formulated with 5.0% BT fed during all 5 feeding phases.

[2]Significant ($P \leq 0.05$) orthogonal contrasts for: A = NC vs. PC diets; B = BT vs. YGr fed in the first 2 phases; C = BT vs. YGr fed in the first 3 phases; and D = BT fed in the early feeding phases vs. BT fed in the late feeding phases.

[3]*t* = *trans*; *c* = *cis*.

Table 12. Effect of phase-feeding dietary fats on the PUFA composition of belly fat samples

Fatty acid composition, %	Dietary treatment[1]						SEM	*P*-value	Contrasts[2]
	NC	BT12	BT123	BT345	BT45	PC			
Total PUFA	20.46[a]	19.14[b]	18.41[bc]	17.24[de]	18.10[cd]	16.98[e]	0.356	<0.01	A, B, D
Linoleic acid (18:2*n*-6)	17.94[a]	16.80[b]	16.09[bc]	15.02[de]	15.80[cd]	14.80[e]	0.324	<0.01	A, B, D
Minor PUFA	1.66[a]	1.56[b]	1.59[b]	1.58[b]	1.60[b]	1.57[b]	0.022	0.02	A
Total CLA[3]	0.36[d]	0.38[c]	0.42[b]	0.47[a]	0.43[b]	0.49[a]	0.007	<0.01	A, B, D
CLA (18:2*c*9*t*11)	0.29[f]	0.32[e]	0.35[d]	0.40[b]	0.36[c]	0.42[a]	0.005	<0.01	A, B, C, D
CLA (18:2*c*9*c*11)	0.05[a]	0.05[b]	0.05[b]	0.05[bc]	0.05[bc]	0.04[c]	0.001	<0.01	A
CLA (18:2*t*9*t*11)	0.02	0.02	0.03	0.02	0.02	0.02	0.002	0.12	B
α-Linolenic acid (18:3*n*-3)	0.85[a]	0.78[b]	0.73[c]	0.65[d]	0.71[c]	0.62[d]	0.014	<0.01	A, B, D
γ-Linolenic acid (18:3*n*-6)	0.03	0.03	0.03	0.02	0.03	0.03	0.003	0.53	
Eicosadienoic acid (20:2)	0.66[a]	0.61[b]	0.59[b]	0.55[c]	0.59[b]	0.53[c]	0.009	<0.01	A, B, D
Dihomo-γ-linolenic acid (20:3*n*-6)	0.13[a]	0.11[b]	0.12[b]	0.11[b]	0.12[a]	0.11[b]	0.002	0.01	A
Arachidonic acid (20:4*n*-6)	0.29[a]	0.27[b]	0.27[ab]	0.26[b]	0.27[b]	0.26[b]	0.007	0.04	A
Other fatty acids peaks	2.33	2.30	2.30	2.36	2.27	2.43	0.043	0.16	
PUFA:SFA[4]	0.64[a]	0.58[b]	0.56[b]	0.52[cd]	0.54[bc]	0.50[d]	0.014	<0.01	A, B, D
Iodine value, mg/g[5]	72.33[a]	70.46[b]	69.97[bc]	68.74[de]	69.34[cd]	67.85[e]	0.435	<0.01	A, B, D

[a,b,c,d,e,f] Within a row, least squares means lacking a common superscript letter differ ($P \leq 0.05$).

[1]NC = grower and finisher diets formulated with 4.7% yellow grease (YGr) fed during all 5 feeding phases; BT12 = diets formulated with 5.0% beef tallow (BT) during the first 2 feeding phases and diets containing 4.7% YGr fed during the last 3 phases; BT123 = diets formulated with 5.0% BT fed during the first 3 phases and diets containing 4.7% YGr fed during the last 2 phases; BT345 = diets containing 4.7% YGr fed during the first 2 feeding phases and diets with 5.0% BT fed during the last 3 phases; BT45 = diets with 4.7% YGr fed during the first 3 phases and diets with 5.0% BT fed during the last 2 phases; and PC = diets formulated with 5.0% BT fed during all 5 feeding phases.

[2]Significant ($P \leq 0.05$) orthogonal contrasts for: A = NC vs. PC diets; B = BT vs. YGr fed in the first 2 phases; C = BT vs. YGr fed in the first 3 phases; and D = BT fed in the early feeding phases vs. BT fed in the late feeding phases.

[3]*t* = *trans*; *c* = *cis*.

[4]The PUFA:SFA ratio was calculated as: [Total PUFA] / [Total SFA], where brackets indicate concentrations.

[5]Iodine value = (0.95 × [∑ 16:1]) + (0.86 × [∑ 18:1]) + (1.732 × [∑ 18:2]) + (2.616 × [∑ 18:3]) + (0.785 × [20:1c11]), where brackets indicate concentrations (AOCS, 1998).

Table 13. Effect of dietary treatments on bacon yields, cooked bacon characteristics, and sensory traits of bacon

	Dietary treatment[1]								
Item	NC	BT12	BT123	BT345	BT45	PC	SEM	*P*-value	Contrasts[2]
Bacon yields, %									
Pump	110.53	110.85	111.08	110.23	110.16	111.28	0.350	0.14	D
Smokehouse	98.18	98.66	98.65	98.04	97.89	98.56	0.367	0.41	D
No. 1 slices	83.84	84.42	82.52	83.38	82.49	83.09	1.257	0.87	
Fat color									
Lightness (L*)[3]	75.38	77.53	75.15	76.48	75.96	76.48	0.969	0.45	
Redness (a*)[3]	2.22	2.07	2.81	2.36	2.25	2.41	0.209	0.23	
Yellowness (b*)[3]	8.99	8.82	8.99	8.97	8.82	8.93	0.125	0.83	
Cook loss, %	73.35	74.01	73.06	74.28	74.51	73.79	0.556	0.35	
Shear force, kg	87.40	85.41	86.29	86.38	88.08	85.23	3.874	0.99	
Sensory traits evaluated									
Initial crispiness[4]	4.06	4.00	4.02	3.99	4.08	3.75	0.192	0.79	
Bacon flavor intensity[5]	5.55	5.33	5.44	5.42	5.43	5.56	0.108	0.60	
Saltiness[6]	5.29	5.06	5.22	5.14	5.21	5.16	0.163	0.94	
Chewiness[7]	4.34	4.28	4.31	4.30	4.27	4.10	0.175	0.93	
Oiliness[8]	6.52	6.55	6.42	6.59	6.53	6.60	0.111	0.84	
Off-flavor intensity[8]	7.75	7.59	7.64	7.61	7.70	7.69	0.067	0.55	

[1]NC = grower and finisher diets formulated with 4.7% yellow grease (YGr) fed during all 5 feeding phases; BT12 = diets formulated with 5.0% beef tallow (BT) during the first 2 feeding phases and diets containing 4.7% YGr fed during the last 3 phases; BT123 = diets formulated with 5.0% BT fed during the first 3 phases and diets containing 4.7% YGr fed during the last 2 phases; BT345 = diets containing 4.7% YGr fed during the first 2 feeding phases and diets with 5.0% BT fed during the last 3 phases; BT45 = diets with 4.7% YGr fed during the first 3 phases and diets with 5.0% BT fed during the last 2 phases; and PC = diets formulated with 5.0% BT fed during all 5 feeding phases.

[2]Significant ($P \leq 0.05$) orthogonal contrasts for: A = NC vs. PC diets; B = BT vs. YGr fed in the first 2 phases; C = BT vs. YGr fed in the first 3 phases; and D = BT fed in the early feeding phases vs. BT fed in the late feeding phases.

[3]L* = a measure of darkness to lightness (greater L* values indicate a lighter color); a* = a measure of redness (greater a* values indicate a redder color); and b* = a measure of yellowness (greater b* value indicates a more yellow color).

[4]1 = extremely crisp to 8 = extremely soft.

[5]1 = extremely bland to 8 = extremely intense.
[6]1 = extremely bland to 8 = extremely salty.
[7]1 = extremely crumbly to 8 = extremely chewy.
[8]1 = abundant to 8 = none.

Figure 1. Effect of dietary treatments on the percentage of other, unidentified fatty acids in backfat and jowl fat samples (NC = grower and finisher diets formulated with 4.7% yellow grease [YGr] fed during all 5 feeding phases; BT12 = diets formulated with 5.0% beef tallow [BT] during the first 2 feeding phases and diets containing 4.7% YGr fed during the last 3 phases; BT123 = diets formulated with 5.0% BT fed during the first 3 phases and diets containing 4.7% YGr fed during the last 2 phases; BT345 = diets containing 4.7% YGr fed during the first 2 feeding phases and diets with 5.0% BT fed during the last 3 phases; BT45 = diets with 4.7% YGr fed during the first 3 phases and diets with 5.0% BT fed during the last 2 phases; and PC = diets formulated with 5.0% BT fed during all 5 feeding phases). Dietary treatments did not ($P \geq 0.17$) affect the concentration of other fatty acids in backfat samples, jowl fat from PC-fed had more ($P < 0.01$) unidentified fatty acids than jowl fat from NC-fed pigs, and pigs fed BT during the first 3 feeding phases had greater ($P < 0.01$) other fatty acids than that from pigs fed YGr during the first 3 phases.

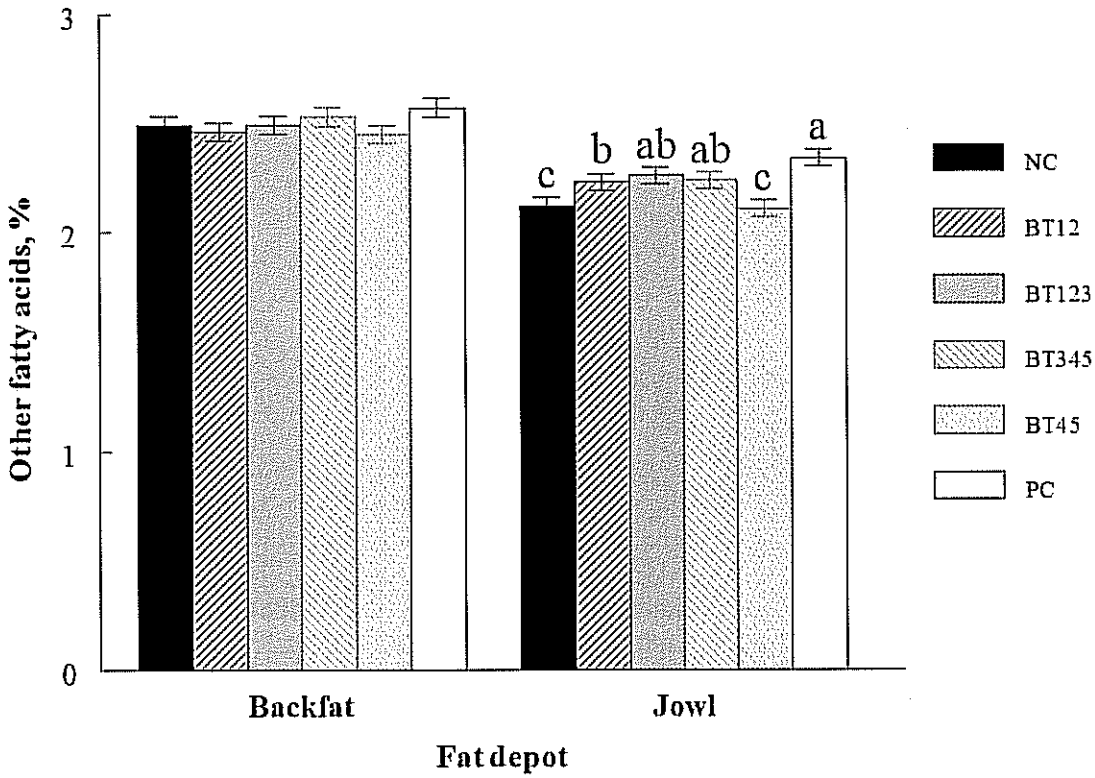


Figure 2. Effect of dietary treatments on the PUFA:SFA in backfat and jowl fat samples (NC = grower and finisher diets formulated with 4.7% yellow grease [YGr] fed during all 5 feeding phases; BT12 = diets formulated with 5.0% beef tallow [BT] during the first 2 feeding phases and diets containing 4.7% YGr fed during the last 3 phases; BT123 = diets formulated with 5.0% BT fed during the first 3 phases and diets containing 4.7% YGr fed during the last 2 phases; BT345 = diets containing 4.7% YGr fed during the first 2 feeding phases and diets with 5.0% BT fed during the last 3 phases; BT45 = diets with 4.7% YGr fed during the first 3 phases and diets with 5.0% BT fed during the last 2 phases; and PC = diets formulated with 5.0% BT fed during all 5 feeding phases). The PUFA:SFA was greater ($P < 0.01$) in backfat from NC-fed than PC-fed pigs, and greater in pigs fed YGr during the later feeding phases than in pigs fed BT during the later phases. Moreover, jowl fat from NC-fed pigs had greater ($P < 0.01$) PUFA:SFA than that from PC-fed pigs.

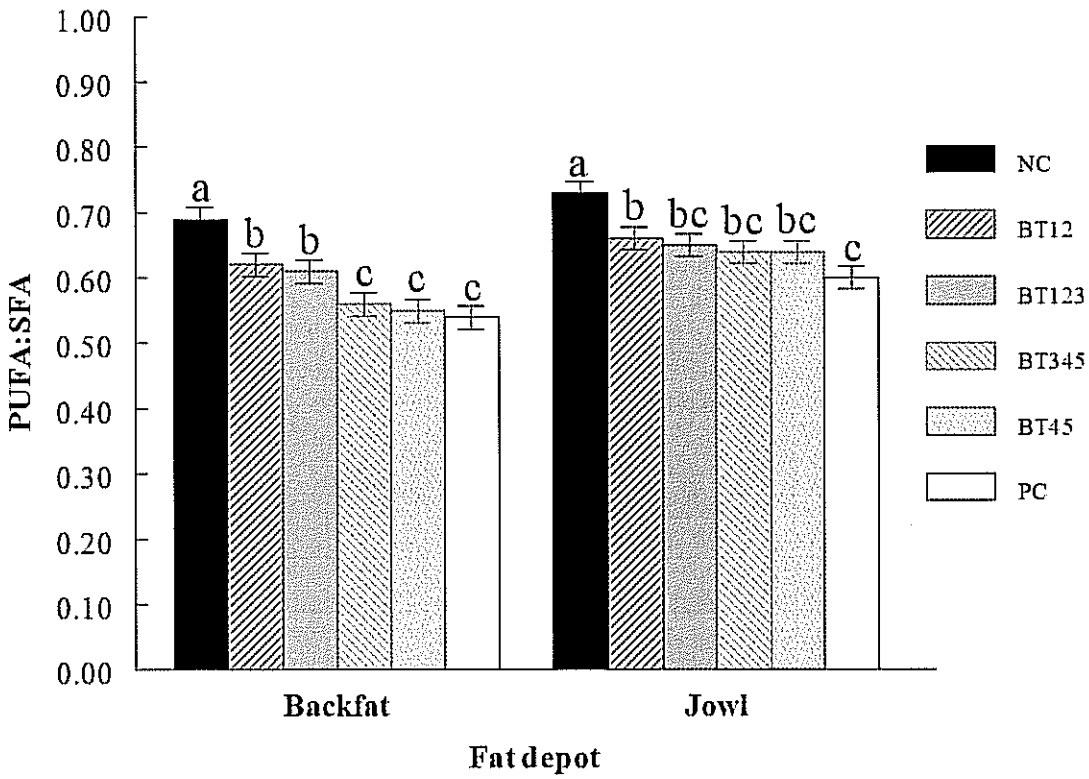
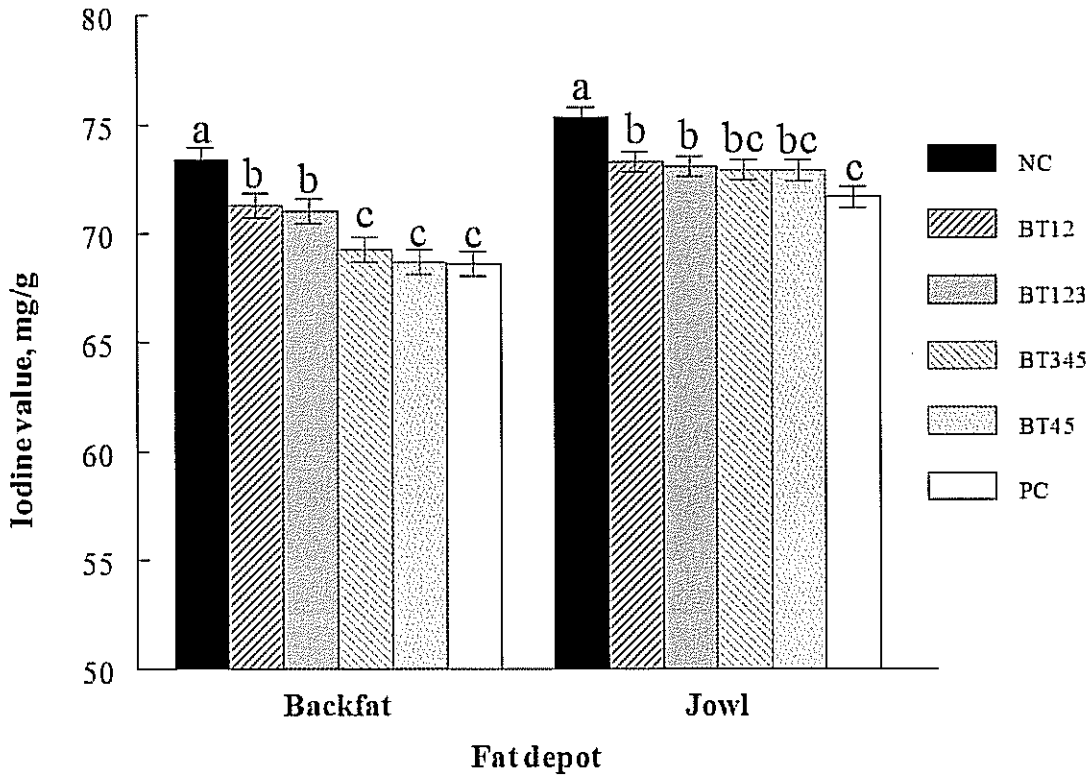


Figure 3. Effect of dietary treatments on the iodine value (IV) of backfat and jowl fat samples (NC = grower and finisher diets formulated with 4.7% yellow grease [YGr] fed during all 5 feeding phases; BT12 = diets formulated with 5.0% beef tallow [BT] during the first 2 feeding phases and diets containing 4.7% YGr fed during the last 3 phases; BT123 = diets formulated with 5.0% BT fed during the first 3 phases and diets containing 4.7% YGr fed during the last 2 phases; BT345 = diets containing 4.7% YGr fed during the first 2 feeding phases and diets with 5.0% BT fed during the last 3 phases; BT45 = diets with 4.7% YGr fed during the first 3 phases and diets with 5.0% BT fed during the last 2 phases; and PC = diets formulated with 5.0% BT fed during all 5 feeding phases). Backfat from NC-fed pigs had greater ($P < 0.01$) IV than backfat from PC-fed pigs, and backfat IV were greater ($P < 0.01$) in pigs fed YGr during the later feeding phases than in pigs fed BT during the later phases. Moreover, jowl fat from NC-fed pigs had greater ($P < 0.01$) IV than that from PC-fed pigs.



Acknowledgements

The principle investigators would like to express their gratitude to the Fats and Protein Research Foundation for funding of this particular project. Moreover, the principle investigators are indebted to Ms. Nicole Browne, who conducted the study to fulfill her requirements for a M.S. degree in Meat Science at the University of Arkansas. The principle investigators are also appreciative of the management and employees of Cargill Meat Solutions (Beardstown, IL) for assistance during hog slaughter and belly collection and transportation, as well as Dane Bonfy and the incredibly helpful employees at Wrights Brand Foods (Vernon, TX) for belly processing and bacon collection. All researchers would like to thank Casey Bradley and Benjamin Bass for pig allotment and performance data collection; Chris Hart, Lindsey Hess, Jarred Wyatt, and Lauren McDonald for animal care; Ryan Stackhouse, Cari Keys-Fuller, Aaron Coffman, and Courtney Moon for assistance with carcass and fresh belly data collection; Tim Johnson for assistance with both fresh belly and bacon data collection; Donna Delozier for assistance with bacon cookery; and Doug Galloway and Heather Pennington for fatty acid analysis.

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