

The effects of dietary fat sources, levels, and feeding intervals on pork fatty acid composition¹

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ABSTRACT: Two experiments investigated the quantitative relationship between dietary fat and fatty acid composition of pork. Experiment 1 was designed to establish the rate of decline for linoleic acid and iodine value of pork fat during the late fattening phase following a dietary reduction. Gilts (n = 288) were fed diets varying in linoleic acid content from 4.11 to 1.56% for 4, 6, or 8 wk prior to slaughter. The maximum rate of decline was 2% 18:2 per week and 2.5 iodine value units per week. Experiment 2 evaluated the effects of dietary fat source and level on carcass fatty acid composition and on pork quality characteristics. Barrows (n = 147) and gilts (n = 147) were allocated to seven dietary treatments for the last 6 wk of the finishing phase. Diets contained 0, 2.5, or 5% dietary fat comprised of

100, 50, or 0% beef tallow. The balance was provided by animal-vegetable blended fat. As the level of tallow increased there was a linear decrease ($P < 0.05$) in 18:2 content and iodine value of carcass fat. Conversely, 16:1 and 18:1 increased linearly ($P < 0.05$) as tallow increased. However, 16:1 decreased linearly ($P < 0.05$) as level of fat increased. As the level of tallow was increased a greater reduction in 18:2 and iodine value was observed in diets with 5% dietary fat compared to diets with 2.5% fat ($P < 0.05$). These results indicate that reduction of dietary PUFA content had the desired effect of lowering 18:2 content and iodine value of pork fat and that significant alterations could be elicited in as little as 6 to 8 wk of feeding.

Key Words: Pigs, Carcass Quality, Fatty Acids, Supplemental Fat, Linoleic Acid

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Introduction

As the pork industry strives for efficient production of increasingly leaner pigs, reduction in fat quality can occur that may adversely affect further processing, tissue separation, and storage stability. Combining extreme leanness in the pig with diets composed of cereal grains and supplemented with fat, often high in polyunsaturated fatty acids (PUFA), in order to maximize grow-finish performance and efficiency can result in soft pork fat. These pork production techniques do help to realize consumer demands for reduced total carcass fat and saturated fatty acids, but this is in conflict with the optimal physical qualities of fat desired for further processing. Consistency and composition of pork fat are quality concerns (Morgan et al., 1994), because thin bellies and soft

fat produce more miscuts and a higher percentage yield of lower-quality product.

It is well established that the fatty acid composition of pork is influenced by the composition of dietary fat (Seerly et al., 1978; Madsen et al., 1992; Miller et al., 1990); however, the quantitative relationship has not been well defined, especially in lean genotype pigs. However, it has been demonstrated (Scott et al., 1983) that there are more saturated fatty acids present in the fat depots of pigs with a genetic predisposition for obesity than in pigs selected for reduced backfat thickness. Wood (1984) reported that PUFA were increased in pigs when fat deposition was reduced by limit feeding as compared to ad libitum intake. The goal of this study was to evaluate nutrition and management programs for lean genotype pigs to maintain production while enhancing pork fat quality. Specifically, our objective was to determine the quantitative relationship between dietary fat and the pork fatty acid profile by manipulating dietary unsaturated fatty acids. This was achieved by reducing linoleic acid content or varying dietary fat sources and levels.

Materials and Methods

Experiment 1 Design. Market gilts (n = 288) from PIC 406 sires × PIC C22 dams were delivered to the North

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Table 1. Composition of diets in Exp. 1 (as-fed basis)

| Item | Soy oil, % | | | |
|-----------------------------------|------------|-------|-------|-------|
| | 100 | 66.7 | 33.3 | 0 |
| Ingredient, % | | | | |
| Corn | 76.10 | 76.10 | 76.10 | 76.10 |
| Soybean meal (48% CP) | 16.60 | 16.60 | 16.60 | 16.60 |
| Soy oil | 5.00 | 3.33 | 1.67 | — |
| Hydrogenated fat | — | 1.67 | 3.33 | 5.00 |
| Limestone | 0.95 | 0.95 | 0.95 | 0.95 |
| Dicalcium phosphate, 21% | 0.69 | 0.69 | 0.69 | 0.69 |
| Salt | 0.38 | 0.38 | 0.38 | 0.38 |
| Lysine-HCl, 95% | 0.13 | 0.13 | 0.13 | 0.13 |
| Trace mineral premix ^a | 0.05 | 0.05 | 0.05 | 0.05 |
| Vitamin premix ^b | 0.05 | 0.05 | 0.05 | 0.05 |
| Virginiamycin 20 | 0.025 | 0.025 | 0.025 | 0.025 |
| Selenium premix ^c | 0.025 | 0.025 | 0.025 | 0.025 |
| Calculated composition | | | | |
| Linoleic acid, % | 4.11 | 3.26 | 2.41 | 1.56 |
| Crude protein, % | 14.2 | 14.2 | 14.2 | 14.2 |
| Lysine, % | 0.82 | 0.82 | 0.82 | 0.82 |
| Phosphorus, % | 0.46 | 0.46 | 0.46 | 0.46 |
| Calcium, % | 0.58 | 0.58 | 0.58 | 0.58 |

^aProvided the following per kg of mix: 166.7 g Zn as ZnO, 166.7 g Fe as FeSO₄, 28.3 g Mn as MnO, 20.2 g Cu as CuSO₄, 70 mg I, and 30 mg Se.

^bProvided the following per kg of mix: 2,268 kIU vitamin A, 340 kIU vitamin D, 9,072 IU vitamin E, 1,134 mg vitamin K, 8.2 mg vitamin B₁, 1,361 mg riboflavin, 6,350 mg d-pantothenate, 9,072 mg niacin, and 2,749 mg menadione.

^cEach kg provided 600 mg Se.

Carolina Swine Evaluation Station at 62 kg and allowed 1 wk to acclimate. Animals were fed the 100% soy oil diet for 3 wk prior to allotment (avg 80 kg) to a 4 × 3 factorial design, blocked by initial weight. Pigs were fed one of four diets varying in polyunsaturated fatty acid (PUFA) content for 4, 6, or 8 wk prior to slaughter. All diets (Table 1) contained 5% added fat, comprised of 100, 66.7, 33.3, or 0% soy oil (Cargill, Fayetteville, NC). The balance was provided by a fully hydrogenated animal fat (Patrick Cudahy, Cudahy, WI). Fatty acid composition of the supplemental fat sources is described in Table 2. Carcass data were obtained from 96 pigs in each slaughter group.

Experiment 2 Design. Barrows (n = 147) and gilts (n = 147) from a PIC 406 sire × PIC C22 female cross were delivered to the North Carolina Swine Evaluation Sta-

tion and allowed a 1-wk period to acclimatize to the facility. Pigs (avg 80 kg) were blocked by initial weight and randomly assigned to one of seven dietary treatments. Dietary treatments (Table 3) varied in percentage dietary fat and dietary fat type and were fed for 6 wk prior to slaughter. Diets contained 0, 2.5, or 5% dietary fat comprised of 0, 50, or 100% beef tallow. The balance was provided by an animal-vegetable fat blend (Table 2).

Live Animal Care and Measurements. All animal procedures were approved by the Institutional Animal Care and Use Committee of North Carolina State University. Pigs and feeders were weighed at 2-wk intervals and feed allotments were weighed daily to determine ADG, ADFI, and feed:gain. Pigs were housed three per pen in a naturally ventilated confinement building with solid concrete floors with 5.6 m² per pig. Feed and water were

Table 2. Analyzed fatty acid composition of the fat sources used in exp. 1 and 2

| Fatty acid | Soy oil | Hydrogenated fat | Animal-vegetable | Tallow |
|----------------------|---------|------------------|------------------|--------|
| 16:0, % ^a | 10.50 | 30.12 | 17.69 | 24.78 |
| 18:0, % | 3.20 | 56.61 | 10.43 | 20.92 |
| 18:1, % | 22.30 | 2.00 | 35.03 | 35.41 |
| 18:2, % | 54.50 | 0.39 | 34.67 | 6.02 |
| 18:3, % | 8.30 | ND ^b | ND | ND |
| Other ^c | 1.20 | 10.88 | 2.18 | 12.87 |
| Iodine value | 132.00 | 2.50 | 97.50 | 41.00 |

^aPercentage by weight.

^bND = not detected.

^cComprised of 3% or less of each of the following fatty acids including: 8:0, 10:0, 12:0, 14:0, 14:1, 15:0, 16:1, 20:0, 20:1, and 20:2.

Table 3. Composition of diets in Exp. 2 (as-fed basis)

| Item | Diet ^a | | | | | | |
|-----------------------------------|-------------------|-------|-------|-------|-------|-------|-------|
| | Control | 2.5AV | 2.5B | 2.5T | 5AV | 5B | 5T |
| Ingredient, % | | | | | | | |
| Corn | 80.85 | 77.06 | 77.06 | 77.06 | 73.22 | 73.22 | 73.22 |
| Soybean meal (48% CP) | 16.65 | 17.95 | 17.95 | 17.95 | 19.30 | 19.30 | 19.30 |
| Tallow | — | — | 1.25 | 2.50 | — | 2.50 | 5.00 |
| Animal-vegetable blend | — | 2.50 | 1.25 | — | 5.0 | 2.50 | — |
| Limestone | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 |
| Dicalcium phosphate, 21% | 0.77 | 0.77 | 0.77 | 0.77 | 0.76 | 0.76 | 0.76 |
| Salt | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Lysine-HCl, 95% | 0.136 | 0.139 | 0.139 | 0.139 | 0.142 | 0.142 | 0.142 |
| Trace mineral premix ^b | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Vitamin premix ^c | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Virginiamycin 20 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 |
| Selenium premix ^d | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 |
| Calculated composition | | | | | | | |
| Diet iodine value | 124.0 | 113.6 | 101.9 | 90.3 | 108.7 | 91.9 | 75.2 |
| Linoleic acid, % | 1.85 | 2.64 | 2.28 | 1.92 | 3.44 | 2.71 | 1.99 |
| Crude protein, % | 14.6 | 14.9 | 14.9 | 14.9 | 15.2 | 15.2 | 15.2 |
| Lysine, % | 0.84 | 0.87 | 0.87 | 0.87 | 0.91 | 0.91 | 0.91 |
| Phosphorus, % | 0.48 | 0.48 | 0.48 | 0.48 | 0.48 | 0.48 | 0.48 |
| Calcium, % | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 |
| ME, kcal/kg | 3,328 | 3,447 | 3,440 | 3,434 | 3,565 | 3,553 | 3,540 |

^aTreatment abbreviations are defined by the amount (2.5 = 2.5%; 5 = 5.0%) and source of supplemental fat: AV = animal-vegetable blend; B = animal-vegetable + tallow blend; T = tallow.

^bProvided the following per kg of mix: 166.7 g Zn, 166.7 g Fe, 28.3 g Mn, 20.2 g Cu, 70 mg I, and 30 mg Se.

^cProvided the following per kg of mix: 2,268 kIU vitamin A, 340 kIU vitamin D, 9,072 IU vitamin E, 1,134 mg vitamin K, 8.2 mg vitamin B₁, 1,361 mg riboflavin, 6,350 mg d-pantothenate, 9,072 mg niacin, and 2,749 mg menadione.

^dEach kg provided 600 mg Se.

available for ad libitum consumption. During the course of the experiments six pigs were removed from Exp. 1 and four pigs were removed from Exp. 2 because of death or failure to thrive.

Adipose tissue samples were collected 3 wk prior to allotment (Exp. 1) and on the day of allotment (Exp. 1 and 2) from one pig per pen by biopsy for fatty acid analysis. Lidocaine (2%, Vet Tek, Blue Springs, MO) was administered as a local anesthetic prior to biopsy. Biopsies were taken with a spring-loaded biopsy device (Biotech Ltd., Slovakia) while animals were restrained in a working chute. The biopsy location was at the 10th rib, approximately 5 cm from the backbone and 2.5 cm deep. Animals were treated with an iodine wound spray after removal of the sample and monitored for signs of infection. Samples were stored under N₂ gas at -80°C until analysis. All other adipose tissue samples were obtained from each pig at slaughter.

Carcass Measurements. All animals were slaughtered in a large commercial facility. Hot carcass weight was determined on-line. Backfat depth and loin muscle depth were measured and lean percentage predicted with the Fat-O-Meater optical probe (SFK Technology A/S, Denmark). Fat-O-Meater measures were taken through a section of the longissimus dorsi between the 3rd and 4th last rib 7 cm off the mid-line split. Carcasses were chilled for 24 h, at which time a 2.5-cm chop was removed between the 9th and 10th ribs. After allowing a minimum of 20 min bloom time, each chop was evaluated for color, ultimate pH, and temperature. The loin chop was mea-

sured in triplicate (middle, medial, and lateral) and mean values were calculated for color lightness (L*), redness (a*), and yellowness (b*) using a Minolta Chromameter 200 (Minolta, Ramsey, NJ). The chromameter was set to D65 illuminant, a 2° standard observer, using an 8-mm optical port with glass insert, and calibrated with Minolta white standard color plate. A visual color score was also determined on a scale from 1 to 6 (1 = pale, 6 = very dark) using plastic Japanese color standards. Japanese color standards are closely related to the Minolta L* value but the scales are in the opposite direction. A lower Minolta L* value indicates a darker color. On the same sample, ultimate pH was measured using an Engold electrode and a K21 pH meter (NWK Binar, Landsberg, Germany). A comparison test of belly firmness (stick test) was conducted by measuring the distance between the outside edges of a belly draped across a smokehouse stick.

Percentage drip loss was estimated by hanging a 100-g loin section removed from between the 9th and 10th rib in a bag for the period from 24 h to 36 h postmortem. The loin section was then reweighed and purge loss was determined.

Backfat tissue cores were taken from each pig from a location approximately 10 cm below the last rib at the midline. Fat samples were placed in N₂ gas at the time of collection and sample preparation and analysis began within 120 min of collection.

Fat firmness was measured using the compression test on the Instron machine. A 1.27-cm core sample was re-

moved from the belly, weighed, and maintained at 4°C until analysis. The sample was compressed to 80% of its original height and the force (kg/g) of compression was determined. The melting point of carcass fat samples was determined using the capillary tube method (AOCS, 1998).

Tissue Analysis. The adipose tissue core samples included the upper layer, middle layer, and the lower layer (including the fascia above the muscle). Following removal of the skin and muscle tissue from the core, the remaining tissue was minced and mixed thoroughly. Lipids were isolated from adipose tissue in duplicate by weighing 100 mg into a glass tube with a Teflon-lined cap. One milliliter of a reagent containing 3.75 M NaOH dissolved in a 1:1 (vol/vol) methanol, distilled water mixture was added and the tubes were heated in a boiling water bath for 5 min, vortexed, and returned to the water bath for 25 min. The samples were then placed into cool water and 2 mL of a 1.7:1 (vol/vol) methyl alcohol and 6.0 N hydrochloric acid mixture was added. The samples were placed into the boiling water bath for 10 min and then immediately placed in cool water. Three milliliters of a 1:1 (vol/vol) methyl tert-butyl ether and hexane mixture was then added to the samples. Samples were vortexed and mixed continuously for 10 min until they were clear and the lower, aqueous phase was discarded. Finally, 3 mL of 0.3 M NaOH was added to the remaining organic layer and the tubes were mixed and centrifuged. Two-thirds of the top, organic, layer was removed to a clean vial and dried under N₂ gas. The methyl esters were redissolved in 250 µL of hexane. A Hewlett Packard 5890 gas chromatograph (Hewlett Packard, Avondale, PA) equipped with a flame ionization detector was used with a 100-m fused silica capillary column with an i.d. of 0.25 mm, a 0.20 µm film coating, and a SP-2380 column stationary phase (Supelco, Bellefonte, PA). Operating conditions were as follows: helium carrier gas, split ratio 1:100, injector temperature 220°C, detector temperature 220°C, initial oven temperature 140°C increasing to 225°C at a rate of 3.2°C/min. The oven was held at 225°C for 14 min, then temperature increased by 2°C/min to 230°C and was held for 6 min. Finally, the temperature was decreased by 8°C/min to 140°C and held for 4 min. Total run time was 65 min. Methyl ester standards were used to identify sample fatty acid methyl esters. Integration software (Millenium, Waters Inc.) was used to calculate the proportion of each fatty acid present. Iodine value was calculated using the following equation: iodine value = 16:1 (0.95) + 18:1 (0.86) + 18:2 (1.732) + 18:3 (2.616) + 20:1 (0.785) + 22:1 (0.723) (AOCS, 1998).

Statistical Analysis. All analyses were conducted using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). Least squares treatment means were obtained assuming fixed models that included the effects of block, diet, time, and diet × time for Exp. 1.

For Exp. 2, least squares treatment means were obtained assuming fixed models that included the effects of block, sex, fat type, percentage of dietary fat, sex × fat type interaction, and sex × percentage dietary fat

interaction. For Exp. 2 the diet degrees of freedom (df) were partitioned into contrasts for linear and quadratic effect of dietary fat level, linear and quadratic effects of dietary fat source, and dietary fat level × dietary fat source interaction. Sex × diet interaction degrees of freedom were partitioned into contrasts for the sex × dietary fat level interaction and the sex × dietary fat source interaction. Fat source, fat level, and interaction least squares means were estimated using a linear function of the model parameters (SAS Inst., Inc., Cary, NC).

Results

Experiment 1

As soy oil was replaced with saturated animal fat, growth rate was unaffected but feed intake from 0 to 8 wk and feed:gain from 0 to 6 wk increased linearly ($P < 0.0001$, Table 4). Combined with data from a digestibility study (Averette Gatlin et al., 2002), these data suggest that the saturated animal fat was not well-digested. No effects of dietary fat composition were detected on final live weight, carcass weight, fat or loin depth, lean percentage, drip loss (Table 5), dressing percentage, pH, loin color (except A reading), or belly color (data not shown). However, a negative quadratic effect ($P < 0.05$) of diet on the loin Minolta-A reading (data not shown) was observed, but this is of questionable biological significance. Both fat depth and loin depth increased with increased time on dietary treatment (linear and quadratic time effect; $P < 0.05$). However, lean percentage decreased linearly ($P < 0.05$) with increased time on dietary treatment. As the PUFA content of the diet was reduced, there was a linear decrease ($P < 0.05$) in 18:2 content of carcass fat. Linoleic acid content also decreased linearly over time ($P < 0.05$). Due to a diet × time interaction, reducing PUFA content reduced iodine values only in gilts fed diets for 6 or 8 wk, but not in those fed for 4 wk. In addition, iodine value decreased linearly only for diets containing 33.3 or 0% soy oil but not for those containing 100 or 66.7% soy oil. The maximum rate of decline (2% 18:2 per week and 2.5 iodine value units per week) was exhibited by gilts fed the diet containing 0% soy oil (diet × time interaction, $P < 0.05$). Conversely, 16:1 and 18:1 increased as the PUFA content of the diet was decreased. For monounsaturate content, the rate of change was greatest for the diet containing 0% soy oil (diet × time interaction, $P < 0.05$). The monounsaturates increased quadratically (positive) with time ($P < 0.05$). No effects on 20:1 content or stick test were detected ($P > 0.10$). Analysis of fatty acid composition of backfat biopsy samples (Figure 1) indicated that 18:2 concentration remained unchanged during the 3-wk pre-test period, averaging about 25%. The collective time course of changes in 18:2 concentration throughout the experiment is illustrated in Figure 1.

Experiment 2

In general, as the level of dietary fat was increased, feed intake and feed:gain decreased linearly ($P < 0.05$,

Table 4. Exp. 1: Effects of dietary fat composition on growth performance (least squares means)

| Item | Diet, % soy oil | | | | Pooled SEM |
|------------------------|-----------------|------|------|------|------------|
| | 100 | 66.7 | 33.3 | 0 | |
| Weeks 0–2, n = 288 | | | | | |
| ADG, kg | 0.92 | 0.94 | 0.89 | 0.90 | 0.02 |
| ADFI, kg ^a | 2.49 | 2.67 | 2.67 | 2.73 | 0.04 |
| Feed:gain ^a | 2.75 | 2.86 | 3.05 | 3.07 | 0.05 |
| Weeks 3–4, n = 288 | | | | | |
| ADG, kg | 0.92 | 0.87 | 0.88 | 0.97 | 0.03 |
| ADFI, kg ^a | 2.77 | 3.04 | 3.07 | 3.20 | 0.06 |
| Feed:gain ^a | 3.01 | 3.53 | 3.54 | 3.75 | 0.09 |
| Weeks 5–6, n = 192 | | | | | |
| ADG, kg | 0.83 | 0.83 | 0.78 | 0.79 | 0.03 |
| ADFI, kg ^a | 3.00 | 3.15 | 3.33 | 3.42 | 0.06 |
| Feed:gain ^a | 3.63 | 3.95 | 4.32 | 4.48 | 0.17 |
| Weeks 7–8, n = 96 | | | | | |
| ADG, kg | 0.87 | 0.99 | 0.93 | 0.99 | 0.06 |
| ADFI, kg ^a | 3.09 | 3.23 | 3.36 | 3.73 | 0.10 |
| Feed:gain ^b | 3.59 | 3.34 | 3.81 | 3.91 | 0.25 |

^aLinear effect of diet ($P < 0.0001$).

^bLinear effect of diet ($P < 0.1$).

Table 6). From d 0 to 42, ADFI and ADG were greater ($P < 0.05$) in barrows than in gilts. However, overall, gilts fed 0% dietary fat were more efficient than gilts fed 2.5% dietary fat, whereas the efficiency of barrows improved linearly with increased dietary fat (sex \times dietary fat level interaction; $P < 0.05$). No effects of dietary fat level or type were detected on carcass weight and drip loss (Table 7). A negative quadratic effect ($P < 0.05$) of dietary fat source on fat depth was observed. Significant sex \times dietary fat source interactions were observed for fat depth ($P < 0.10$), muscle depth ($P < 0.05$), and lean percentage ($P < 0.05$) (Table 7). For lean percentage of barrows a quadratic effect of dietary fat source was observed. The quadratic responses are of questionable biological significance because the total depth of fat and muscle appears not to differ between sexes. Dietary fat source resulted in no significant differences in lean percentage of gilts.

As the level of tallow in the diet was increased, the monounsaturates, 16:1 and 18:1, increased linearly. However, 16:1 decreased linearly as the percentage of dietary fat in the diet increased. As the level of dietary tallow increased a greater reduction in 18:2 (Figure 2) and iodine value (Table 7) was observed in diets with 5% dietary fat compared to diets with 2.5% dietary fat (dietary fat level \times dietary fat source interaction; $P < 0.05$). Diet 5T caused a greater reduction in 18:2 and iodine value than diets 2.5AV, 2.5B, 5AV, and 5B ($P < 0.05$). In contrast, diet 5AV, in which a 100% animal-vegetable blend was supplemented to the diet at 5%, resulted in a significantly higher ($P < 0.05$) 18:2 content and iodine value of carcass fat than diets Cntrl, 2.5B, 2.5T, 5B, and 5T. The linoleic acid content of backfat in relation to daily dietary intake (based on the pen average intake) of linoleic acid is depicted in Figure 3.

Discussion

To reduce the risk of atherosclerosis and coronary heart disease in humans, the American Heart Association has recommended that 30% of dietary energy come from fat with an even distribution of polyunsaturated, monounsaturated, and saturated fatty acids (Neville, 1990). Because the fatty acid profile of carcass lipids in pigs is easily altered, responds to changes in dietary fat composition, and has the potential to be modified to match dietary recommendations for humans, several researchers have measured the change in fatty acid composition following dietary manipulation (Koch et al., 1968; Anderson et al., 1972; Wiseman and Agunbiade, 1998). The majority of these changes appear in the first 25 d but they have not been well quantified (Wood et al., 1994).

To optimize the level and type of fat to be used in a swine diet, it would be beneficial to know how these two factors affect the resulting fatty acid profile and meat quality, and how long the fat source should be fed to achieve the desired results. The data on linoleic acid intake from Exp. 1 and 2, shown in Figure 3, provide a means to determine the amount and level of a fat source to feed depending on the linoleic acid concentration in the final diet and the desired concentration of linoleic acid in the carcass backfat. Anderson et al. (1972) measured the half-life of linolenic acid as an estimate of fatty acid turnover. Their value of 300 d in an 8- to 12-month pig was determined by feeding two barrows a diet containing 20% linseed oil for 2 mo and then measuring the decline in linolenate back to normal tissue levels. In addition, the half-life was 175 d in ether-extractable muscle lipids and 47 d in muscle membrane lipids (Anderson et al., 1972).

Table 5. Exp. 1: Effects of dietary fat composition fed for 4, 6, or 8 wk on carcass characteristics, backfat unsaturated fatty acid content, iodine value, fat firmness, fat melting point, and stick test (least squares means)^a

| Item | 4 wk | | | 6 wk | | | 8 wk | | | Pooled SEM | | |
|-------------------------------------|------------------|------|-------|-------|------|------|------|------|------|------------|------|------|
| | Diet, % soy oil: | 66.7 | 33.3 | 0 | 100 | 66.7 | 33.3 | 0 | 100 | | 66.7 | 33.3 |
| Live wt, kg ^b | 105 | 108 | 103 | 103 | 114 | 117 | 115 | 114 | 125 | 128 | 128 | 129 |
| Carcass wt, kg ^b | 77 | 80 | 77 | 76 | 85 | 88 | 87 | 84 | 95 | 96 | 96 | 96 |
| Fat depth, mm ^{bc} | 15.8 | 17.6 | 16.0 | 16.6 | 19.5 | 19.8 | 22.4 | 19.4 | 21.8 | 20.8 | 22.1 | 20.4 |
| Loin depth, mm ^{bc} | 51.4 | 46.3 | 50.4 | 49.5 | 58.0 | 58.0 | 55.4 | 54.6 | 58.3 | 57.2 | 57.8 | 57.5 |
| Lean percentage ^b | 55.4 | 53.7 | 55.1 | 54.7 | 53.9 | 53.7 | 51.8 | 53.6 | 52.6 | 53.0 | 52.3 | 53.3 |
| Drip loss, % ^c | 3.8 | 3.4 | 3.4 | 3.8 | 4.9 | 4.9 | 5.9 | 4.3 | 3.6 | 3.1 | 4.0 | 3.7 |
| 16:1, % ^{bedef} | 2.42 | 2.49 | 2.40 | 2.43 | 2.16 | 2.28 | 2.47 | 2.70 | 2.44 | 2.59 | 2.66 | 3.21 |
| 18:1, % ^{bedef} | 38.7 | 39.0 | 39.4 | 38.9 | 36.9 | 38.7 | 39.2 | 40.8 | 38.4 | 39.6 | 39.9 | 42.9 |
| 20:1, % ^f | 0.67 | 0.80 | 0.80 | 0.79 | 0.95 | 0.83 | 0.71 | 0.69 | 0.81 | 0.91 | 0.82 | 0.67 |
| Iodine value ^{bede} | 81.7 | 79.3 | 81.6 | 82.3 | 86.1 | 83.6 | 78.4 | 76.2 | 84.2 | 80.8 | 76.7 | 72.6 |
| Fat firmness, kg ^{bee} | 93.9 | 98.2 | 112.8 | 114.0 | 70.1 | 72.2 | 67.6 | 79.9 | 82.3 | 77.8 | 93.8 | 89.3 |
| Fat melting point, °C ^{de} | 34.6 | 34.1 | 34.2 | 34.3 | 34.4 | 34.7 | 34.4 | 34.5 | 33.6 | 33.6 | 33.4 | 33.6 |
| Stick test, cm ^c | 11.2 | 10.9 | 10.9 | 11.7 | 11.9 | 11.7 | 12.2 | 12.7 | 9.1 | 12.2 | 10.9 | 9.4 |

^aEach value is the mean of eight pens of three pigs each.

^bLinear time effect ($P < 0.05$).

^cQuadratic time effect ($P < 0.05$).

^dDiet × time interaction ($P < 0.05$).

^eLinear diet effect ($P < 0.05$).

^fPercentage by weight.

Due to the development of lean genotype pigs since that time, new data are needed regarding how the level of inclusion, fat source, and length of time fed can affect the fatty acid turnover and composition of pork. In other modeling work, a decrease in fat depth of 10 mm was associated with an increase of 4 iodine value units (Barton-Garde, 1984). Similarly, Wood et al. (1978) measured increased 18:2 concentrations in lean, fast-growing lines. Rates of de novo fat synthesis are also reduced in genetically lean pigs compared to pigs with a genetic disposition for fat deposition (Steele et al., 1974). In addition, diet enrichment of specific fatty acids decreased de novo lipogenesis, the reduction depending on fatty acid chain length and degree of unsaturation (Smith et al., 1996). Further, pigs with a reduced capacity for lipogenesis appear to have a greater rate of lipolysis (Standal et al., 1973; Wood et al., 1977). A reduction in adipose tissue accretion has also been observed in porcine somatotropin (pST)-treated pigs, resulting in decreased fat depth over the 10th rib (Lonergan et al., 1992). The effect of pST on backfat depth has been attributed to a reduction in lipogenesis without a concurrent change in fatty acid composition (Dunshea et al., 1992; Lonergan et al., 1992). However, because the depth of the more saturated middle and inner backfat layers was reduced more than the outer layer (Lonergan et al., 1992), the unsaturated fatty acid content of samples containing all three layers could increase proportionally.

More recently, using a modern lean genotype, Wiseman and Agunbiade (1998) determined that the changes in tissue fatty acid concentrations are indeed rapid. They estimated that 60 to 70% of the theoretical capacity for change was reached in the first 2 wk following dietary changes. They noted that the rate and the amount of change that may occur depend on several factors, including initial tissue concentrations. In our study, tissue linoleic acid concentration did not appear to increase during the 3-wk loading period of Exp. 1 (Figure 1). An experiment conducted by Warnants et al. (1999) used the opposite approach. Pigs first consumed a diet containing 2.5% tallow to increase tissue lipid saturation. Then, researchers measured the increasing degree of unsaturation as pigs consumed a diet containing 15% full-fat soybeans (FFS). After 6 wk, the backfat PUFA content of the pigs consuming the FFS was not different from that of pigs fed the FFS for 8 wk, indicating a plateau had been reached. Our results are in agreement and indicate that 6 to 8 wk of feeding a supplemental fat source will significantly alter the backfat fatty acid profile and may improve pork processing characteristics depending on the supplemental fat source.

Our study confirms findings from other laboratories that backfat fatty acid composition reflects dietary fat composition (Seerley et al., 1978; Miller et al., 1990; Madsen et al., 1992). In Exp. 1, fat firmness increased as soy oil was removed from the diet and the proportions of 18:2 decreased but 16:1, 18:0, and 18:1 increased (Table 5). Increasing tallow in the diet (Exp. 2) resulted in similar changes in the carcass fatty acid profile. Piedrafit

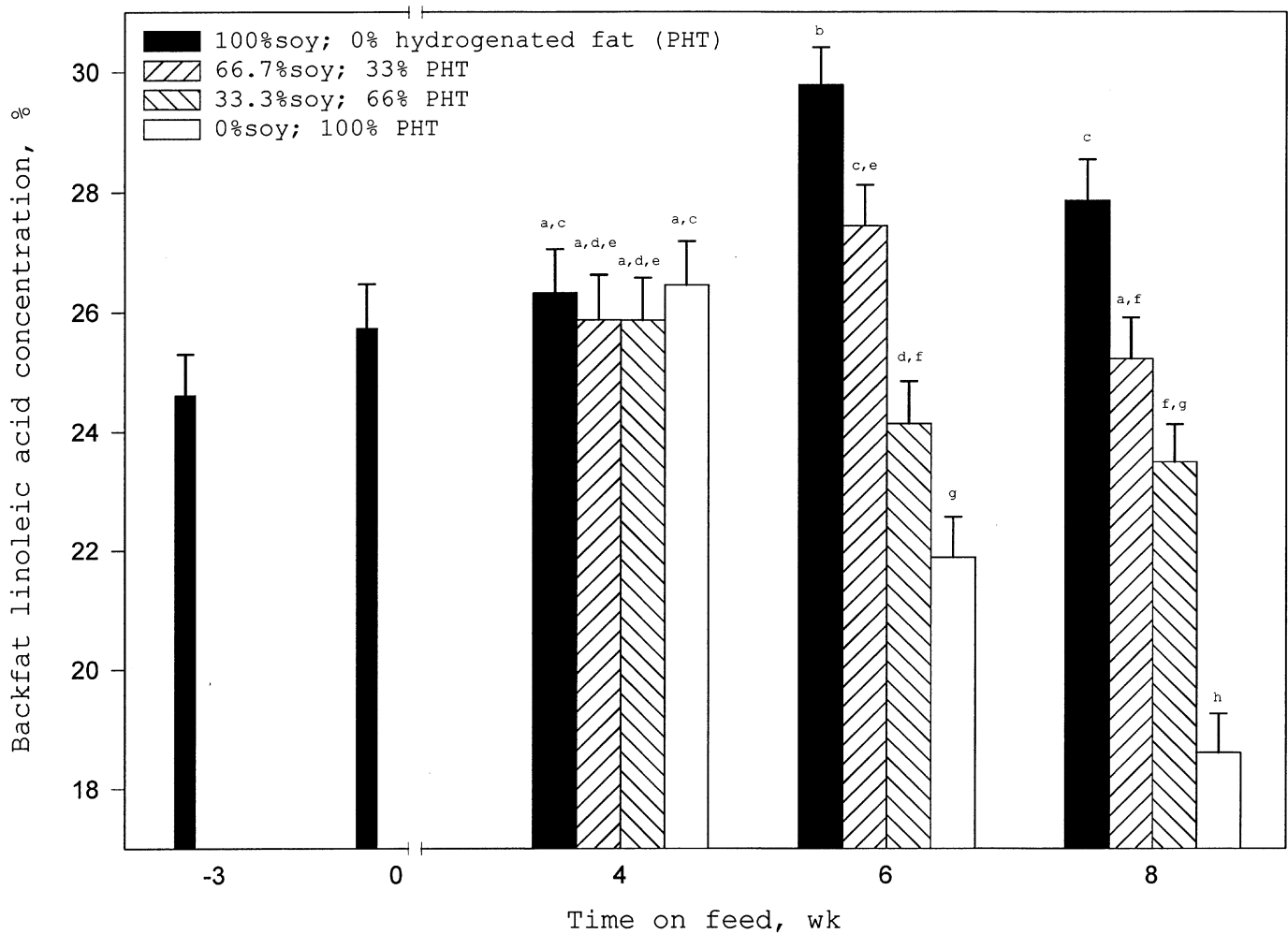


Figure 1. Time course of changes in linoleic acid content of backfat from gilts fed diets varying in fat composition (Exp. 1). Data are least square means ($n = 24$ /treatment). Error bars represent \pm SEM. Bars lacking a common letter differ ($P < 0.05$). Linoleic acid means at 0 and -3 wk ($n = 96$) are not statistically compared because those means include all animals prior to allocation of treatments. Linear diet effect ($P < 0.05$). Linear time effect ($P < 0.05$). Diet \times time interaction ($P < 0.05$). †Percentage by weight.

et al. (2001) noted a positive correlation between fat firmness and 16:0 and 16:1 and a negative correlation with 18:2 and 18:3. They concluded that the degree of fat firmness was correlated to the proportion of total unsaturated fatty acids. In addition, animals with a greater amount of lean also had a greater amount of linoleic acid in backfat (Nürnberg et al., 1998). They observed that other fat parameters were negatively correlated to linoleic acid concentration. This relationship is exaggerated in lean-genotype animals and animals fed unsaturated fat sources, resulting in softer carcass fat and increasing processing difficulty. Our study supports this finding and shows that supplemental dietary fat sources containing lower levels of linoleic acid result in reduced backfat linoleic acid levels (Figure 3). It has been recommended that PUFA levels should not exceed 23% in backfat used for salami manufacture for acceptable processing and product acceptability (Warnants et al., 1998). Furthermore, Houbend and Krol (1980) deter-

mined that pork products produced from pigs consuming diets leading to 30% backfat linoleic acid concentrations were highly susceptible to lipid oxidation.

One approach that may be taken in an effort to improve the tissue lipid saturation is to remove supplemental fat from the diet. When a very low fat diet is fed, de novo fat synthesis produces saturated and monounsaturated fatty acids. Research done by Engel et al. (2001) supports this theory; they found decreasing levels of saturated fats in the longissimus muscles of pigs fed choice white grease or poultry fat regardless of level of inclusion. In addition, linoleic acid concentration in the longissimus muscle was greater in those animals consuming 4 or 6% fat compared to those fed the control diet ($P < 0.05$). This response was linear with respect to increasing fat level of the diet, but the magnitude of the response was small ($< 2\%$). In Exp. 2 of our work, 5% supplemental tallow resulted in a lower backfat linoleic acid concentration and a lower iodine value compared to the 0% supplemen-

Table 6. Exp. 2: Effects of dietary fat level and type on growth performance (least squares means)

| Item ^a | Female (n = 147) | | | | | | | Castrate (n = 147) | | | | | | | Pooled SEM |
|--------------------------|------------------|-------|------|------|------|------|------|--------------------|-------|------|------|------|------|------|------------|
| | Cntrl | 2.5AV | 2.5B | 2.5T | 5AV | 5B | 5T | Cntrl | 2.5AV | 2.5B | 2.5T | 5AV | 5B | 5T | |
| Days 0–14 | | | | | | | | | | | | | | | |
| ADG, kg ^{bcd} | 1.08 | 0.93 | 0.88 | 0.98 | 0.99 | 0.93 | 1.00 | 1.11 | 1.13 | 0.93 | 1.06 | 1.14 | 1.16 | 1.17 | 0.05 |
| ADFI, kg ^{de} | 2.52 | 2.62 | 2.60 | 2.65 | 2.36 | 2.39 | 2.31 | 3.15 | 2.97 | 2.79 | 2.88 | 2.72 | 2.97 | 2.93 | 0.13 |
| Feed:gain ^{bce} | 2.53 | 2.91 | 2.78 | 2.77 | 2.43 | 2.65 | 2.37 | 2.91 | 2.71 | 3.07 | 2.64 | 2.46 | 2.58 | 2.57 | 0.11 |
| Days 15–28 | | | | | | | | | | | | | | | |
| ADG, kg | 0.91 | 0.94 | 0.92 | 0.97 | 0.98 | 0.93 | 0.98 | 1.03 | 0.97 | 0.96 | 0.93 | 0.94 | 1.05 | 0.98 | 0.04 |
| ADFI, kg ^{bdef} | 3.17 | 3.12 | 2.99 | 3.07 | 2.90 | 2.94 | 2.84 | 3.78 | 3.41 | 3.18 | 3.23 | 3.23 | 3.54 | 3.31 | 0.10 |
| Feed:gain ^{de} | 3.56 | 3.45 | 3.33 | 3.33 | 3.02 | 3.23 | 2.93 | 3.72 | 3.73 | 3.42 | 3.56 | 3.49 | 3.46 | 3.51 | 0.14 |
| Days 29–42 | | | | | | | | | | | | | | | |
| ADG, kg ^g | 0.98 | 0.93 | 1.01 | 1.01 | 1.02 | 1.07 | 1.00 | 0.92 | 1.14 | 0.88 | 0.91 | 1.01 | 0.91 | 0.98 | 0.05 |
| ADFI, kg ^{de} | 3.29 | 3.25 | 3.27 | 3.32 | 2.96 | 3.14 | 3.04 | 3.63 | 3.65 | 3.27 | 3.30 | 3.41 | 3.5 | 3.27 | 0.12 |
| Feed:gain ^{de} | 3.52 | 3.61 | 3.39 | 3.36 | 3.00 | 3.04 | 3.11 | 4.15 | 3.25 | 3.84 | 3.80 | 3.47 | 3.45 | 3.42 | 0.17 |
| Days 0–42 | | | | | | | | | | | | | | | |
| ADG, kg ^d | 0.97 | 0.92 | 0.93 | 0.94 | 0.97 | 0.97 | 0.94 | 0.93 | 1.10 | 0.90 | 0.98 | 1.02 | 1.05 | 1.02 | 0.05 |
| ADFI, kg ^{de} | 3.05 | 3.08 | 3.18 | 3.04 | 2.81 | 2.93 | 2.68 | 3.31 | 3.64 | 3.21 | 3.14 | 3.22 | 3.40 | 3.21 | 0.13 |
| Feed:gain ^f | 3.17 | 3.39 | 3.43 | 3.32 | 2.80 | 3.04 | 2.89 | 3.78 | 3.37 | 3.57 | 3.23 | 3.21 | 3.29 | 3.20 | 0.14 |

^aDiet abbreviations are defined by the amount (2.5 = 2.5%; 5 = 5.0%) and source of supplemental fat: AV = animal-vegetable blend; B = animal-vegetable + tallow blend; T = tallow.

^bQuadratic effect of dietary fat level ($P < 0.05$).

^cQuadratic effect of dietary fat source ($P < 0.05$).

^dSex effect ($P < 0.05$).

^eLinear effect of dietary fat level ($P < 0.05$).

^fSex \times dietary fat level interaction ($P < 0.05$).

^gSex \times dietary fat source interaction ($P < 0.05$).

tal fat control, although the magnitude of the change was small ($< 1\%$). Leszczynski et al. (1992) also fed a diet containing tallow and found levels of 18:2 in bacon similar to that in animals consuming a 0% supplemental fat control diet after 3 and 6 wk.

No significant sex differences in the proportion of fatty acids were noted (Table 7). Others have noted differences in individual fatty acids: gilts had a higher proportion of 16:0, 18:2, and 18:3 than barrows (Piedrafita et al., 2001). However, there was a sex \times fat level interaction for 18:1. Barrows fed 2.5 or 5% supplemental fat had a reduced proportion of 18:1. The proportion of 18:1 did not change with varying levels of supplemental fat in gilts. Data from a study comparing boars and gilts suggested that a sex effect on fatty acid composition was independent of varying backfat depths (Wood et al., 1989). The type of supplemental fat had a more predictable effect on backfat depth of gilts than of barrows (Table 7; sex \times fat type interaction). Supplemental fats resulted in increased backfat depth in gilts, but not in barrows. It is known that gilts are leaner than barrows at similar slaughter weights (Enser, 1991; Warnants et al., 1998). However, the pattern of fatty acid changes should not be dependent on sex (Warnants et al., 1999).

Dietary fat appears to have a greater effect on bacon than on the loin muscle because the two sites may have different levels of sensitivity to direct incorporation of linoleic and linolenic acid (Leszczynski et al., 1992). This difference in sensitivity resulted in increased concentrations of linoleic acid in belly muscle compared to the longissimus muscle in the same animal (Leszczynski et al., 1992). Camara et al. (1996) measured increased lipo-

genic enzyme activities in backfat compared to the longissimus dorsi muscle, again suggesting that the fat layers that are present in bacon may be more sensitive to dietary changes. In addition, the half-life or turnover rate of fatty acids, specifically linolenate, has been shown to vary from 47 to 300 d, depending on the adipose tissue depot measured (Anderson et al., 1972).

Many studies have noted decreased feed intake and increased gain/feed (**G/F**) with increasing level of supplemental dietary fat (Bayley and Lewis, 1963; Seerley et al., 1978; Engel et al., 2001). In trial 1, ADFI increased ($P < 0.0001$) with decreasing amounts of soy oil. Even though the balance was provided by hydrogenated fat, the apparent digestibility was low and intake increased to compensate for the reduced caloric density (L. Averette Gatlin, unpublished data). Overall, gain, intake, and feed efficiency were not affected by the source of dietary fat in Exp. 2 ($P > 0.10$).

In conclusion, reduction of dietary PUFA content had the desired effect of lowering the 18:2 content and iodine value of pork fat as expected; however, the magnitude of the reduction (from 26% to 18.6% 18:2 and from 86 to 76 iodine value: Exp. 1) was less than desired. This was likely due to the limited digestibility of the saturated animal fat (L. Averette Gatlin, unpublished data). In Exp. 2, reduction of dietary fat level and the substitution of tallow for animal-vegetable blend fat in the diet had the desired effects of lowering the 18:2 content and iodine value of pork fat as expected. However, the magnitude of the reduction (from 21.2% to 17.5% 18:2 and from 78.1 to 73.2 iodine value) again was less than desired. Furthermore, although dietary PUFA content affected

Table 7. Exp. 2: Effects of dietary fat level and type on carcass characteristics, backfat unsaturated fatty acid content, iodine value and stick test (least squares means)

| Item ^a | Female | | | | | | Castrate | | | | | | SEM | |
|-----------------------------|--------|-------|-------|-------|-------|-------|----------|-------|-------|-------|-------|-------|-------|-------|
| | Cntrl | 2.5AV | 2.5B | 2.5T | 5AV | 5B | 5T | Cntrl | 2.5AV | 2.5B | 2.5T | 5AV | | 5B |
| Carcass wt, kg ^b | 90 | 91 | 90 | 92 | 91 | 92 | 92 | 94 | 92 | 92 | 94 | 94 | 95 | 94 |
| Fat depth, mm ^c | 18.3 | 21.2 | 20.3 | 19.2 | 19.5 | 20.5 | 20.9 | 24.6 | 23.2 | 26.8 | 23.9 | 24.6 | 26.9 | 23.5 |
| Loin depth, mm ^d | 53.3 | 52.6 | 53.2 | 54.8 | 54.8 | 56.9 | 51.7 | 48.6 | 50.9 | 47.5 | 53.1 | 50.7 | 49.3 | 53.0 |
| Lean, % ^d | 54.1 | 52.2 | 52.8 | 53.7 | 53.6 | 53.2 | 52.3 | 49.7 | 50.8 | 48.2 | 50.7 | 50.0 | 48.4 | 50.9 |
| Drip loss, % | 3.37 | 3.24 | 2.94 | 2.82 | 2.94 | 3.14 | 2.85 | 3.32 | 2.46 | 3.04 | 3.58 | 2.85 | 3.08 | 3.29 |
| 16:1, % ^{ef} | 2.96 | 2.81 | 2.81 | 2.88 | 2.61 | 2.76 | 2.96 | 2.99 | 2.75 | 2.75 | 2.97 | 2.77 | 2.80 | 2.83 |
| 18:1, % ^{fg} | 41.1 | 40.9 | 42.3 | 42.2 | 40.7 | 41.2 | 42.8 | 42.1 | 40.3 | 41.0 | 41.6 | 40.6 | 41.8 | 42.3 |
| 20:1, % | 0.48 | 0.61 | 0.57 | 0.63 | 0.61 | 0.55 | 0.53 | 0.59 | 0.67 | 0.66 | 0.51 | 0.54 | 0.57 | 0.57 |
| Iodine value ^{hh} | 71.4 | 73.4 | 73.2 | 71.2 | 76.0 | 73.7 | 70.2 | 70.5 | 71.5 | 71.8 | 72.5 | 73.3 | 71.3 | 69.9 |
| Stick test, cm ^b | 13.69 | 13.69 | 13.16 | 12.40 | 13.64 | 13.74 | 12.70 | 15.09 | 13.46 | 14.07 | 13.46 | 14.50 | 15.67 | 14.50 |

^aDiet abbreviations are defined by the amount (2.5 = 2.5%; 5 = 5.0%) and source of supplemental fat: AV = animal-vegetable blend; B = animal-vegetable + tallow blend; T = tallow.

^bSex effect ($P < 0.05$).
^cSex × dietary fat source interaction ($P < 0.10$).
^dSex × dietary fat source interaction ($P < 0.05$).
^eLinear effect of dietary fat level ($P < 0.05$).
^fLinear effect of dietary fat source ($P < 0.05$).
^gSex × dietary fat level interaction ($P < 0.05$).
^hDietary fat level × dietary fat source interaction ($P < 0.05$).

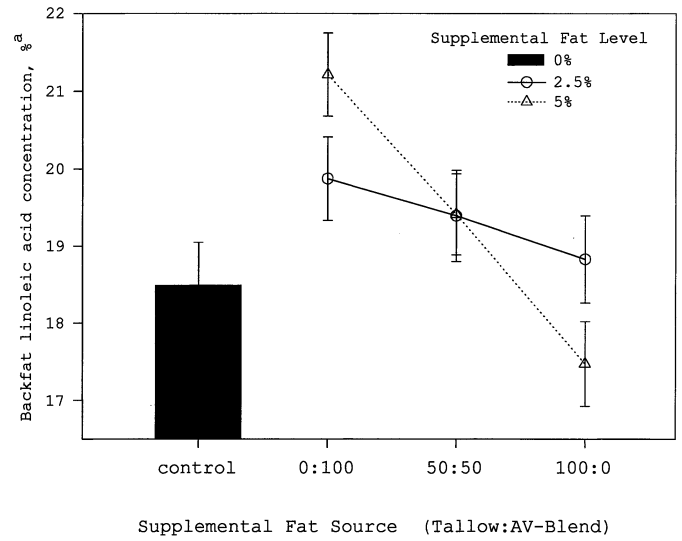


Figure 2. Effects of dietary fat level and composition on backfat linoleic acid concentration (Exp. 2). Data are least squares means ($n = 42$ /treatment). Error bars represent \pm SEM. Dietary fat level × dietary fat source interaction ($P < 0.05$). ^aPercentage by weight.

carcass fatty acid composition, no major effects on measured carcass characteristics (firmness, melting point, and stick test) were detected. This may indicate that these carcass characteristics are not reliable measures of firmness, and ultimately it is not known how they relate to belly processing. An increase in saturation of carcass fat (iodine value down to 68 to 70) would likely

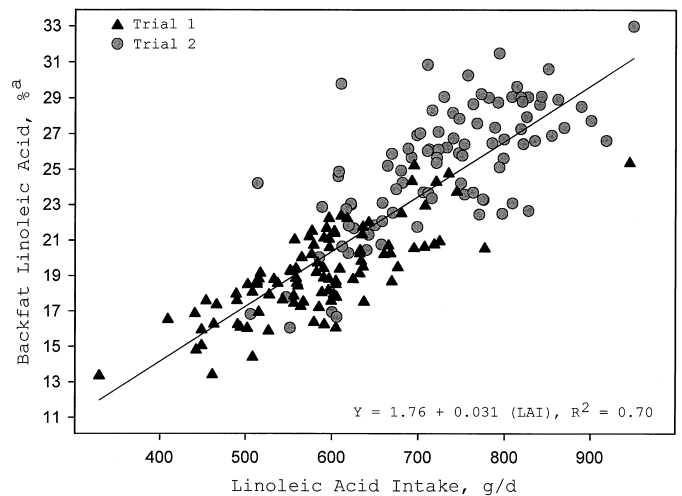


Figure 3. Carcass linoleic acid content (Y) is correlated to the amount of total dietary linoleic acid (LAI). Data points represent actual linoleic acid intake of individual animals ($n = 96$ /trial). Graph represents the regression of daily linoleic acid intake on carcass linoleic acid composition for both trials. Regression for Trial 1: $Y = 6.61 + 0.021$ (LAI), $R^2 = 0.59$. Regression for Trial 2: $Y = 6.28 + 0.062$ (LAI), $R^2 = 0.49$. ^aPercentage by weight.

result in improved processing and other pork quality attributes. Based on these findings, future research should utilize saturated fat of higher digestibility and should include additional assessment of the effects on other pork-processing characteristics.

Implications

Reducing the linoleic acid content of diets for swine during the 6 to 8 wk prior to slaughter will result in a reduction in linoleic acid and iodine value of pork fat. Further, lowering the amount of linoleic acid is associated with increasing amounts of monounsaturated fatty acids in the carcass. The shift toward a more saturated fatty acid profile as a result of altering the dietary fat level and source will likely improve further processing. The reduction of dietary linoleic acid resulted in a 2 iodine value unit decrease per week, and this rate may likely be increased with supplementation of an even more saturated fat source and/or lengthening the period in which the fat source is fed, especially in pigs with a backfat depth of < 18 mm.

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