

# Hydrogenated dietary fat improves pork quality of pigs from two lean genotypes<sup>1,2</sup>

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**ABSTRACT:** Pork quality is influenced by nutrition, genetics, management, and pork-processing procedures. Pigs of lean genotype fed diets high in unsaturated fat may have thinner, lower-quality bellies with a soft fat composition. Therefore, we investigated the effects of supplementing 5% choice white grease that had been chemically hydrogenated to iodine values of 80, 60, 40, or 20 on pork quality. Diets were fed to barrows and gilts of two genotypes (NPD [Ham-line × Manor hybrid] and PIC [406, 419, or 420 × C22]; n = 240) in a 4 × 2 × 2 factorial design. Pigs (76.8 kg of mean initial weight) were placed on test at a common age and were fed dietary treatments for 52 d. Pigs of PIC genotype were heavier at trial initiation, had higher feed intake and feed conversion ratio (F/G;  $P < 0.05$ ), and greater backfat (26.3 vs. 24.0 mm;  $P < 0.001$ ) and loin depth (59.0 vs. 55.3 mm;  $P < 0.001$ ) compared with the NPD genotype pigs. As the iodine value of dietary fat was reduced, belly thickness increased ( $P < 0.05$ ) and length decreased linearly ( $P < 0.05$ ). Congru-

ently, belly fat iodine value decreased from 73.9 to 67.4 (linear effect;  $P < 0.001$ ) and belly fat C18:2 concentration declined from 20.6 to 16.3% (linear and quadratic effect;  $P < 0.001$ ). The belly mono- and polyunsaturated fat ratio increased 29% as diet iodine value declined from 80 to 20 (linear and quadratic effect;  $P < 0.001$ ). Further, there was a linear increase ( $P < 0.001$ ) in saturated fatty acid concentration of belly fat (C14:0, C16:0, and C18:0) as dietary fat iodine value declined. Quadratic ( $P < 0.005$ ) effects were detected in the level of C18:1*trans* as iodine value decreased from 80 to 20, paralleling dietary content. Dietary fat iodine value did not affect fat digestibility, ADFI, or F/G. Pork belly quality was improved as defined by reduced iodine value, C18:2 content, increased saturated fatty acid content, increased thickness, and decreased length as dietary iodine value decreased. Results indicate that reduction of dietary fat iodine value by chemical hydrogenation has the desirable effect of improving pork quality and does not alter growth performance.

Key Words: Fatty Acids, Hydrogenated Fats, Meat Quality, Pork, Pigs

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## Introduction

The pork industry has realized an increasing demand for pork bellies due to increased consumption of bacon among U.S. consumers. Nutrition, genetics, management, and pork-processing technique influence belly quality. Indeed, the very practices employed by the industry to enhance efficient production of lean meat may

result in bellies of lower quality. Soft, thin bellies (<25.4 mm) result in more mis-cuts and yield a higher percentage of class 2 (lower quality) products (Morgan et al., 1994). Further, the thinner bellies may be associated with a reduction in fat quality, which can adversely affect further processing, tissue separation, and storage stability. The quality of pork fat can be defined as color, consistency, and keeping quality, and is affected by both the size of fat depots in the pig and dietary fat composition.

Research has established (Seerley et al., 1978; Miller et al., 1990; Madsen, 1992) that the final fatty acid profile of pork carcass fat reflects the relative contribution of each dietary fat source. In addition, Scott et al. (1983) observed that fatty acids present in the fat depots of pigs with a genetic predisposition for obesity were more saturated than in pigs selected for reduced backfat thickness. Results from our laboratory indicate that a reduction in C18:2 content of swine adipose tissue is achieved when tallow is added to a corn-soybean meal-based diet

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

Ingredient	%
Corn	77.66
Soybean meal (48% CP)	15.35
Partially hydrogenated fat (Iodine value 80, 60, 40, or 20)	5.00
Defluorinated phosphate (18% P)	0.92
Limestone	0.51
Salt	0.27
L-Lysine HCl (78.8% lysine)	0.13
Vitamin/trace mineral premix <sup>a</sup>	0.14
BMD 60 <sup>b</sup>	0.025
Calculated content	
ME, kcal/kg	3,573
Lysine, %	0.79
Linoleic acid, %	2.16
Calcium, %	0.55
Phosphorus, total %	0.49

<sup>a</sup>Supplied per kilogram of complete diet: 5,535 IU of vitamin A as retinyl acetate, 1,110 IU of vitamin D<sub>3</sub>, 22 IU of vitamin E as DL- $\alpha$ -tocopherol acetate, 2 mg of vitamin K as menadione dimethylpyrimidinol bisulfite, 165 mg of choline as choline chloride, 22 mg of niacin, 17.6 mg of D-pantothenic acid as DL-calcium pantothenate, 4.4 mg of riboflavin, 1.1 mg of pyridoxine as pyridoxine-HCl, 0.57 mg of thiamine as thiamine mononitrate, 22  $\mu$ g of vitamin B<sub>12</sub>, 0.34 mg of folic acid, 38.8  $\mu$ g of D-biotin, 110 mg of Zn as ZnSO<sub>4</sub>, 110 mg of Fe as FeSO<sub>4</sub>, 22 mg of Cu as CuSO<sub>4</sub>, 55 mg of Mn as MnO, 0.28 mg of iodine as ethylenediamine dihydriodine, and 0.30 mg of Se as Na<sub>2</sub>SeO<sub>3</sub>.

<sup>b</sup>Supplied 18.5 mg of bacitracin methylene disalicylate per kilogram of diet.

or when tallow replaces less saturated sources of dietary fat (Averette Gatlin, 2002b). Because an insufficient amount of saturated fat is available in the Southeastern states, and chemical hydrogenation might provide a viable alternative, our objectives were to evaluate the effects of partially hydrogenated, choice white grease on performance, carcass fatty acid composition and pork processing. In addition, our objectives included the evaluation of the effects of genotype, and its interaction with dietary fat on performance, carcass fatty acid composition, and pork processing.

## Materials and Methods

All animal procedures were approved by the Institutional Animal Care and Use Committee of North Carolina State University. Barrows and gilts (n = 240) of two commercially relevant genetic lines: NPD (Ham-line  $\times$  Manor hybrid; Roanoke Rapids, NC) and PIC (406, 419, or 420  $\times$  C22; Franklin, KY) were provided by Murphy Farms, Inc. (Rose Hill, NC). Animals were farrowed during a 1-wk period and delivered at weaning to the North Carolina Swine Evaluation Station at an average weight of 5.8 kg. Animals were raised on conventional nursery and finishing programs to an average weight of 76.8 kg. One week prior to allocation to experimental diets, a single standard diet formulated with 5% supplemental fat (animal-vegetable blend) was fed. Four test diets (Table 1) were formulated to 0.79% lysine and 3,573 kcal of ME/kg. Each of the four dietary treatments were supplemented at a 5% level with choice white grease that had been partially hydrogenated to an iodine value (IV)

of 80, 60, 40, or 20 (provided by Chemol, Inc., Greenville, NC). Fatty acid profiles of all supplemented fats are listed in Table 2. Pigs were allotted (three pigs per pen) to a 4  $\times$  2  $\times$  2 factorial design replicated over two slaughter groups wherein pigs were grouped by initial weight within genotype, gender, and location in the building.

Adipose tissue samples were collected upon allotment to treatment by biopsy from each of eight pigs selected randomly from each genetic source  $\times$  gender subclass for subsequent fatty acid analysis as previously described (Averette Gatlin et al., 2002b). 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 N<sub>2</sub> gas at -80°C until analysis.

Animals were fed one of the dietary treatments for 52 d prior to slaughter at approximately 130 kg. Feed weight was recorded and all pigs and feeders were weighed every 2 wk for calculation of growth performance variables on a pen basis (n = 80).

**Carcass Measurements.** Pigs were individually tattooed prior to slaughter and sent to a commercial facility. Hot carcass weight was determined online. Backfat depth and loin muscle depth were measured and lean percentage was predicted with real-time ultrasound (AUSKEY, Ithaca, NY). Measures were obtained through a section of the longissimus dorsi, 7 cm off the mid-line split at the 10th rib. Carcasses were chilled for 24 h, at which time the full boneless loins (3 mm trim) were evaluated subjectively for firmness on a 1 to 5 scale, with 1 = soft and 5 = firm (National Pork Board, 2000). A 2.5-cm chop was removed from the loin at a location approximately between the 9th and 10th ribs. After allowing a minimum of 10 min of bloom time, each chop was evaluated for color and ultimate pH. The loin chop was measured 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) as previously described (Averette Gatlin, 2002b). A visual color score was also determined on a scale from 1 to 6 (1 = pale, 6 = very dark) using plastic Japanese color standards (National Pork Board, 2000). Marbling scores were determined subjectively using a visual scale (1 = 1% intramuscular fat, 6 = 6%) (National Pork Board, 2000). On the same sample ultimate pH (24 h) was measured using an Engold electrode and a K21 pH meter (NWK Binar, Landsberg, Germany).

Backfat tissue cores were taken from each carcass from a location approximately 10 cm below the last rib at the midline. Fat samples were also collected from the belly and loin. Fat samples were placed in N<sub>2</sub> gas at the time of collection and stored at -80°C until analysis. Boned, rough-cut, skin-on bellies were laid on a table to determine thickness by measuring height from the table surface. Belly thickness and length were measured in four locations: dorsal, ventral, ham end, and shoulder end.

**Table 2.** Fatty acid composition of partially hydrogenated choice white grease

Fatty acid, weight %	Iodine value			
	20	40	60	80
16:0	25.79	24.40	23.82	23.11
16:1 <i>cis</i>	0.46	0.41	0.30	0.26
18:0	51.27	30.73	13.95	8.94
18:1 <i>trans</i>	11.46	18.41	10.37	1.16
18:1 <i>cis</i>	8.59	22.62	37.54	33.15
18:2	ND	0.31	7.68	28.91
18:3	ND	0.15	ND	0.44
Other <sup>a</sup>	2.43	2.97	6.34	4.03
Calculated iodine value <sup>b</sup>	18.7	38.5	57.6	85.4
Saturated, %	79.26	57.83	43.68	35.11
Monounsaturated, %	20.74	41.71	48.64	35.54
Polyunsaturated, %	0.0	0.46	7.68	29.35
U/S ratio <sup>c</sup>	0.26	0.73	1.29	1.85

<sup>a</sup>Comprised of 3% or less of each of the following fatty acids including: C8:0, C10:0, C12:0, C14:0, C14:1, C20:0, C20:1, and C20:2.

<sup>b</sup>Calculated using the following equation: C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723) (AOCS, 1998).

<sup>c</sup>Weight ratio of unsaturated (monounsaturates + polyunsaturates) to saturated fatty acids.

**Tissue Analysis.** The adipose tissue core samples included the upper layer, middle layer, and lower layer (including the fascia below 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 and analyzed by gas chromatography as previously described (Averette Gatlin et al., 2002b). Methyl ester standards were used to identify sample fatty acid methyl esters. Integration software (Millenium, Waters, Inc., Milford, MA) was used to calculate the proportion of each fatty acid present. Iodine value was calculated using the following equation (AOCS, 1998):

$$\text{C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723)}$$

**Statistical Analysis.** An ANOVA was conducted using the GLM procedure of SAS (SAS Inst., Inc., Cary, NC) appropriate for a 4 × 2 × 2 factorial design, with pen as the experimental unit. Least squares treatment means were obtained assuming fixed models that included the effects of block, diet, genotype, gender, and all significant interactions of diet, genotype, and gender. The diet df were partitioned into contrasts for linear and quadratic effects of supplemental fat iodine level (SAS Inst., Inc.). Data were not adjusted to a common end weight; therefore, results are more descriptive of animals being fed to a common age, rather than weight. Differences were considered significant when  $P \leq 0.05$ . Trends were noted when  $0.10 > P > 0.05$ .

## Results

### Effects on Growth and Carcass Characteristics

Growth performance was influenced by genotype and gender (Table 3), but not by dietary fat (Table 4). Animals were compared at a constant age, so initial weights were

lower for gilts than for barrows and lower for NPD than for PIC animals (Table 3,  $P < 0.01$ ). Because NPD gilts weighed less throughout the trial, that difference impacted upon other measures during the experiment as expected. Correspondingly, barrows had greater ADG than gilts, especially for the NPD genotype (genotype × gender,  $P < 0.05$ ). Barrows consumed more feed ( $P < 0.01$ ) and were less efficient (higher feed:gain [F/G],  $P < 0.01$ ) than gilts. Similarly, animals of the PIC genotype consumed more feed ( $P < 0.001$ ) and had higher F/G ( $P < 0.05$ ). Increasing saturation (decreasing IV) of supplemental dietary fat had no effect on growth performance (Table 4). Differences in fat digestibility (owing to the IV of the partially hydrogenated fats) were not detected (previously reported; Averette et al., 1999) and were supported by the equivalent rates of growth and feed intake.

At the end of the study, the live weight, hot carcass weight, and cold carcass weight of NPD gilts were 10.9, 11.3, and 11.7% lower, respectively, than all other genotype × gender subclasses (genotype × gender interaction;  $P < 0.05$ ; Table 3). In addition, NPD gilts had 24.2% less backfat ( $P < 0.05$ ) and 7.0% more lean ( $P < 0.01$ ). Belly weight of NPD gilts was 17.4% lower than all other animals ( $P < 0.05$ ; genotype × gender interaction). Furthermore, boneless loin weight was 5.4% greater in PIC pigs ( $P < 0.01$ ; Table 4) and 7.9% greater in barrows ( $P < 0.001$ ; Table 3). In addition, loin depth was 6.6% greater in PIC pigs ( $P < 0.001$ ).

Ultimate pH was 3.0% lower in the longissimus dorsi from PIC pigs ( $P < 0.003$ ; Table 5). Minolta a\* and b\* values were higher for PIC than for NPD animals ( $P < 0.01$ ), and loin firmness score was higher for NDP than for PIC pigs ( $P < 0.01$ ).

There were minimal effects of dietary fat composition on gross carcass measurements (Table 4) or measures of longissimus dorsi quality (Table 5). An interaction between diet and gender on fat depth was noted ( $P <$

**Table 3.** Effects of genotype and gender on growth performance and carcass characteristics of pigs consuming diets supplemented with partially hydrogenated fat<sup>a</sup>

Item	NPD		PIC		Pooled SEM
	Barrow	Gilt	Barrow	Gilt	
Initial weight, kg <sup>bc</sup>	77.4	69.6	82.6	77.3	0.8
ADG, kg <sup>cd</sup>	1.09	0.99	1.09	1.07	0.02
ADFI, kg <sup>bc</sup>	3.14	2.72	3.30	3.04	0.06
F/G, kg/kg <sup>ce</sup>	2.88	2.74	3.05	2.84	0.05
Live weight at slaughter, kg <sup>bcd</sup>	135.4	120.9	132.3	139.4	1.4
Hot carcass weight, kg <sup>bcd</sup>	97.9	86.8	101.1	94.9	1.1
Cold carcass weight, kg <sup>bcd</sup>	96.9	85.8	100.7	94.0	1.1
Boneless loin weight, kg <sup>bef</sup>	5.50	4.94	5.59	5.40	0.09
Belly weight, kg <sup>bcd</sup>	9.26	7.69	9.68	8.98	0.18
Fat depth, mm <sup>bcd</sup>	27.7	20.3	28.3	24.3	0.8
Loin depth, mm <sup>b</sup>	54.8	55.8	58.6	59.4	1.3
Carcass lean, % <sup>c</sup>	48.73	53.30	49.12	51.62	0.56

<sup>a</sup>Each mean represents 20 pens with three pigs per pen.

<sup>b</sup>Genotype main effect ( $P < 0.001$ ).

<sup>c</sup>Gender main effect ( $P < 0.01$ ).

<sup>d</sup>Genotype  $\times$  gender interaction ( $P < 0.05$ ).

<sup>e</sup>Genotype main effect ( $P < 0.05$ ).

<sup>f</sup>Genotype  $\times$  gender interaction ( $P < 0.07$ ).

0.05), with greater depth in barrows consuming diets containing more saturated dietary fat. However, belly measurements were affected by dietary fat (Table 6). Specifically, belly thickness and length were increased and reduced, respectively, with increasing saturation of supplemental dietary fat. Decreasing the IV of dietary fat increased belly thickness linearly on both dorsal and ventral sides ( $P < 0.05$ ) and linearly decreased belly length on ham ( $P < 0.05$ ) and shoulder ( $P < 0.05$ ) ends. Ventral thickness was 9.8% greater in gilts compared to barrows ( $P < 0.001$ ; data not shown). No treatment effects were detected on the thickness of the shoulder end. Belly length on the dorsal and ventral sides was 2% greater and length on the shoulder side was 4% greater

in barrows compared to length in gilts ( $P < 0.01$ ; data not shown).

#### Effects on Fatty Acid Composition

Alterations in fatty acid composition of the belly fat, 10th-rib backfat, and longissimus dorsi intramuscular fat are outlined in Tables 7 to 10. Changes in fatty acid composition of all carcass fat depots reflected to varying degrees the fatty acid composition of the diet (Table 2), with effects on intramuscular fat being less pronounced. Thus, as the IV of dietary fat was reduced by chemical hydrogenation; the IV of belly and backfat depots were each reduced linearly by 9% ( $P < 0.05$ ). This effect was

**Table 4.** Effect of dietary fat hydrogenation and genotype on carcass characteristics of lean genotype pigs<sup>a</sup>

Item	NPD				PIC				Pooled SEM
	IV <sup>b</sup> 20	IV 40	IV 60	IV 80	IV 20	IV 40	IV 60	IV 80	
Initial weight, kg <sup>c</sup>	73.7	73.6	73.3	73.6	81.0	79.7	79.4	79.7	1.1
ADG, kg <sup>d</sup>	1.00	1.04	1.07	1.07	1.09	1.07	1.09	1.07	0.03
ADFI, kg <sup>c</sup>	2.85	2.92	3.06	2.88	3.30	3.12	3.13	3.13	0.08
F/G, kg/kg <sup>c</sup>	2.86	2.78	2.89	2.70	3.02	2.92	2.88	2.96	0.08
Live weight at slaughter, kg <sup>cd</sup>	127.8	127.7	127.8	129.4	137.7	135.7	134.4	135.6	2.0
Hot carcass weight, kg <sup>cd</sup>	92.5	91.6	92.8	92.3	99.8	97.5	97.0	97.7	1.5
Cold carcass weight, kg <sup>cd</sup>	91.9	90.8	91.4	91.4	99.6	96.9	96.4	96.4	1.6
Belly weight, kg <sup>cd</sup>	8.38	8.50	8.42	8.60	9.53	9.31	9.42	9.06	0.25
Boneless loin weight, kg <sup>c</sup>	5.15	5.13	5.21	5.38	5.58	5.38	5.45	5.57	0.12
Fat depth, mm <sup>cde</sup>	24.5	25.5	22.3	23.7	27.0	26.1	26.0	26.1	1.1
Loin depth, mm <sup>c</sup>	54.9	55.0	55.8	55.6	56.4	59.3	59.0	61.3	1.8
Carcass lean, %	50.63	50.05	52.13	51.25	49.47	50.55	50.56	50.91	0.79

<sup>a</sup>Each mean represents 10 pens with three pigs per pen.

<sup>b</sup>IV = iodine value of supplemented dietary fat.

<sup>c</sup>Genotype main effect ( $P < 0.01$ ).

<sup>d</sup>Genotype  $\times$  gender interaction ( $P < 0.05$ ); refer to Table 3.

<sup>e</sup>Gender  $\times$  diet interaction ( $P < 0.05$ ): Fat depth means for gilts and barrows fed fats with IV of 20, 40, 60, and 80 were 23.3, 22.0, 20.0, and 24.0 and 28.2, 29.6, 28.3, and 25.8, respectively, with a pooled SEM of 1.1 mm.

**Table 5.** Effect of dietary fat hydrogenation and genotype on longissimus dorsi quality of lean genotype pigs<sup>a</sup>

Item	NPD				PIC				Pooled SEM
	IV <sup>b</sup> 20	IV 40	IV 60	IV 80	IV 20	IV 40	IV 60	IV 80	
Ultimate pH (24hr) <sup>c</sup>	5.90	6.07	5.94	6.00	5.71	5.83	5.88	5.79	0.08
Minolta color									
L*	42.22	40.01	44.04	40.33	45.43	43.57	42.23	43.73	1.29
a* <sup>c</sup>	6.62	7.32	6.05	6.96	8.07	8.49	8.09	8.26	0.40
b* <sup>c</sup>	1.49	1.25	1.54	1.21	3.63	3.10	2.58	3.24	0.40
Japanese color score	3.67	3.96	3.31	3.70	2.97	3.36	3.67	3.45	0.23
Marbling score	2.38	2.01	2.17	2.20	2.26	2.04	2.28	2.38	0.19
Firmness score <sup>c</sup>	3.79	3.91	3.43	3.71	2.95	3.19	3.46	3.02	0.20

<sup>a</sup>Each mean represents 10 pens with three pigs per pen.

<sup>b</sup>IV = iodine value of supplemented dietary fat.

<sup>c</sup>Genotype main effect ( $P < 0.01$ ).

predicated on increasing concentrations of saturated fatty acids (e.g., C16:0 and C18:0;  $P < 0.05$ ) and decreasing PUFA, especially C18:2 (linear and quadratic reductions,  $P < 0.001$ ), in belly and backfat depots that were congruent with changes in supplemental dietary fat composition. Similarly, increasing linear and quadratic ( $P < 0.05$ ) effects were observed in the concentration of C18:1*trans* in belly and backfat, closely mirroring the concentration in the supplemental dietary fat (Table 2).

In contrast to belly and backfat depots, the IV and saturated fatty acid concentrations of longissimus dorsi intramuscular fat (Table 9), were not influenced by dietary fat composition. However, PUFA concentration of intramuscular fat did directly reflect dietary fat, driven largely by C18:2 concentration. Indeed, linoleic acid in the intramuscular loin fat was lower than in belly or backfat depots, but still declined 16% as diet IV was reduced ( $P < 0.001$ ). Similarly, C18:1*trans* content of intramuscular fat from loin samples changed quadratically ( $P < 0.001$ ), reflecting the content in dietary fat. Although this pattern remained the same, the magni-

tudes of change for each diet varied slightly across gender and genotype ( $P < 0.05$ ; Figure 1).

Genotype differences also were seen in several fatty acids. In belly fat, C16:0 concentration was 3.9% higher in PIC pigs ( $P < 0.05$ ; Table 7), whereas the C18:0 concentration tended to increase more in NPD pigs compared to PIC pigs (genotype  $\times$  diet interaction;  $P < 0.08$ ) as diet IV declined. These differences led to an overall higher calculated IV of the belly fat in NPD pigs ( $P < 0.05$ ). Further, PIC pigs tended to respond more linearly with increasing saturates and decreasing unsaturated:saturated fat (U:S) ratio as diet IV declined than NPD pigs (genotype  $\times$  diet interaction;  $P < 0.08$ ). However, the U:S ratio of intramuscular fat samples from NPD pigs was 3.3% higher than PIC pigs ( $P < 0.05$ ; Table 9). Finally, a trend for an interaction of genotype and gender was noted for C18:3 ( $P < 0.01$ ) and polyunsaturate concentrations ( $P < 0.07$ ) within intramuscular fat (Table 10). Within the NPD genotype, C18:3 was higher in gilts than in barrows, whereas in PIC animals, it was higher in barrows. But the concentration of PUFA overall was

**Table 6.** Effect of dietary fat hydrogenation and genotype on belly thickness and length in lean genotype pigs<sup>a</sup>

Item	NPD				PIC				Pooled SEM
	IV <sup>b</sup> 20	IV 40	IV 60	IV 80	IV 20	IV 40	IV 60	IV 80	
Thickness, mm									
Dorsal side <sup>c</sup>	27.0	24.4	24.2	23.7	28.4	27.6	26.8	24.5	1.4
Ventral side <sup>c</sup>	31.0	30.7	29.9	29.5	32.5	32.3	30.2	29.7	1.1
Ham end <sup>cd</sup>	37.7	39.3	38.1	32.8	38.7	37.6	40.7	35.2	1.4
Shoulder end	55.9	53.7	52.5	53.0	52.6	54.3	55.1	53.1	1.2
Length, cm									
Dorsal	68.5	69.7	68.0	68.5	69.3	69.8	69.5	68.8	0.6
Ventral <sup>de</sup>	63.9	65.0	63.2	62.6	64.3	66.0	65.2	64.2	0.7
Ham <sup>c</sup>	30.5	28.8	31.4	32.0	31.1	30.9	31.6	32.5	0.9
Shoulder <sup>ce</sup>	49.5	51.0	52.5	53.2	52.9	52.1	52.9	54.2	0.6

<sup>a</sup>Each mean represents 10 pens with three pigs per pen.

<sup>b</sup>IV = iodine value of supplemented dietary fat.

<sup>c</sup>Linear effect of diet ( $P < 0.05$ ).

<sup>d</sup>Quadratic effect of diet ( $P < 0.05$ ).

<sup>e</sup>Genotype main effect ( $P < 0.001$ ).

**Table 7.** Effect of partially-hydrogenated dietary fat supplementation and genotype on fatty acid composition, levels of saturates, monounsaturates (MUFA), and polyunsaturates, and iodine values of pork belly fat samples<sup>a</sup>

Fatty acid, weight %	NPD				PIC				Pooled SEM
	IV <sup>b</sup> 20	IV 40	IV 60	IV 80	IV 20	IV 40	IV 60	IV 80	
C14:0 <sup>c</sup>	1.5	1.4	1.4	1.4	1.6	1.5	1.4	1.4	0.1
C16:0 <sup>cd</sup>	22.2	20.9	20.6	21.2	22.8	22.3	21.8	21.4	0.4
C16:1 <sub>cis</sub>	2.2	2.2	2.2	2.3	2.4	2.2	2.2	2.2	0.1
C18:0 <sup>de</sup>	11.6	10.3	9.7	9.4	10.6	10.9	10.1	9.3	0.4
C18:1 <sub>trans</sub> <sup>cf</sup>	1.6	2.5	1.6	0.8	1.7	2.5	1.4	0.7	0.1
C18:1 <sub>cis</sub>	38.5	39.0	39.0	38.0	38.3	37.9	39.0	38.3	0.5
C18:2 <sup>cf</sup>	16.3	16.7	18.4	20.9	16.4	16.2	17.4	20.4	0.5
C18:3	0.7	0.7	0.6	0.7	0.6	0.7	0.6	0.6	0.1
C20:1 <sub>cis</sub>	1.0	0.9	1.1	0.9	1.0	0.8	1.0	1.0	0.1
Calculated IV <sup>cd</sup>	67.4	69.2	71.5	74.4	67.5	67.4	69.4	73.4	0.8
Saturated, % <sup>cde</sup>	35.4	32.7	31.8	32.2	35.2	34.8	33.5	32.2	0.6
Monounsaturated, % <sup>cf</sup>	43.4	44.7	44.0	42.3	43.5	43.5	43.7	42.3	0.4
Polyunsaturated, % <sup>cf</sup>	17.4	17.7	19.5	21.9	17.4	17.2	18.4	21.5	0.5
Mono:poly ratio <sup>cf</sup>	2.5	2.6	2.3	1.9	2.5	2.5	2.4	2.0	0.1
U:S ratio <sup>cde</sup>	1.7	1.9	2.0	2.0	1.7	1.7	1.9	2.0	0.04

<sup>a</sup>Each mean represents 10 pens with three pigs per pen.

<sup>b</sup>IV = iodine value of supplemented dietary fat.

<sup>c</sup>Linear effect of diet ( $P < 0.001$ ).

<sup>d</sup>Genotype main effect ( $P < 0.05$ ).

<sup>e</sup>Genotype  $\times$  diet interaction ( $P < 0.08$ ).

<sup>f</sup>Quadratic effect of diet ( $P < 0.001$ ).

higher in gilts of both genotypes, with the magnitude of difference being greater in NPD than in PIC animals.

## Discussion

Slicing of pork bellies for bacon can be hindered if the belly is thin and/or has soft fat composition. As genetics

companies have placed selection emphasis on backfat reduction, a leaner belly also is produced. Combining extreme leanness in the pig with diets composed of cereal grains and supplemented with fat that is often high in PUFA in order to maximize grower-finisher performance and efficiency can result in soft fat composition. During interviews conducted for the Pork Chain Quality Audit

**Table 8.** Effect of partially-hydrogenated dietary fat supplementation and genotype on fatty acid composition, levels of saturates, monounsaturates (MUFA), and polyunsaturates, and iodine values of pork 10th-rib backfat samples<sup>a</sup>

Fatty acid, weight %	NPD				PIC				Pooled SEM
	IV <sup>b</sup> 20	IV 40	IV 60	IV 80	IV 20	IV 40	IV 60	IV 80	
C14:0	1.50	1.5	1.4	1.5	1.5	1.6	1.5	1.4	0.1
C16:0 <sup>c</sup>	21.5	21.3	21.0	20.7	21.7	22.0	21.6	21.1	0.4
C16:1 <sub>cis</sub>	2.0	2.0	2.0	2.0	2.0	2.1	2.2	2.1	0.1
C18:0 <sup>d</sup>	11.8	10.7	10.6	9.6	10.2	11.1	10.2	9.5	0.4
C18:1 <sub>trans</sub> <sup>df</sup>	1.9	2.7	1.8	0.9	1.6	2.7	1.6	0.8	0.2
C18:1 <sub>cis</sub>	34.7	35.8	36.9	34.8	34.7	35.2	36.1	36.4	0.6
C18:2 <sup>de</sup>	18.1	18.1	18.6	21.9	17.8	17.9	19.1	22.3	0.6
C18:3	0.5	0.6	0.6	0.7	0.6	0.6	0.6	0.6	0.1
C20:1 <sub>cis</sub> <sup>cf</sup>	1.0	0.9	1.0	1.2	0.9	0.9	1.1	1.1	0.1
Calculated IV <sup>d</sup>	67.2	68.9	69.9	72.8	66.5	68.4	70.2	74.5	1.1
Saturates, % <sup>d</sup>	34.9	33.6	33.2	32.0	33.6	34.8	33.4	32.1	0.7
Monounsaturated, % <sup>e</sup>	40.0	41.9	41.8	38.5	39.5	41.5	41.4	39.8	0.6
Polyunsaturated, % <sup>de</sup>	18.6	18.7	19.2	22.5	18.4	18.5	19.7	22.9	0.6
Mono:poly ratio <sup>de</sup>	2.2	2.3	2.2	1.7	2.2	2.3	2.1	1.8	0.7
U:S ratio <sup>d</sup>	1.7	1.8	1.8	1.9	1.7	1.7	1.8	2.0	0.04

<sup>a</sup>Each mean represents 10 pens with three pigs per pen.

<sup>b</sup>IV = iodine value of supplemented dietary fat.

<sup>c</sup>Linear effect of diet ( $P < 0.05$ ).

<sup>d</sup>Linear effect of diet ( $P < 0.001$ ).

<sup>e</sup>Quadratic effect of diet ( $P < 0.001$ ).

<sup>f</sup>Quadratic effect of diet ( $P < 0.05$ ).

**Table 9.** Effect of partially-hydrogenated dietary fat supplementation and genotype on fatty acid composition, levels of saturates, monounsaturates (MUFA), and polyunsaturates, and iodine values of longissimus dorsi intramuscular fat samples<sup>a</sup>

Fatty acid, weight %	NPD				PIC				Pooled SEM
	IV <sup>b</sup> 20	IV 40	IV 60	IV 80	IV 20	IV 40	IV 60	IV 80	
C14:0	1.8	1.8	1.7	1.9	2.1	1.8	2.1	1.8	0.2
C16:0	22.9	22.8	22.6	22.9	25.0	22.4	24.3	22.4	1.4
C16:1 <i>cis</i>	3.2	3.2	3.0	3.3	3.6	3.0	3.6	3.2	0.2
C18:0	10.6	10.3	10.2	9.6	10.6	10.4	10.1	9.8	0.7
C18:1 <i>trans</i> <sup>def</sup>	1.1	1.5	1.1	0.8	1.0	1.4	1.1	0.6	0.1
C18:1 <i>cis</i>	34.0	35.7	35.4	35.4	36.1	33.2	36.5	33.9	2.0
C18:2 <sup>d</sup>	10.9	10.9	11.9	13.4	10.9	10.4	12.2	11.8	0.7
C18:3 <sup>e</sup>	0.2	0.4	0.5	0.4	0.5	0.4	0.6	0.4	0.1
C20:1 <i>cis</i>	0.2	0.4	0.3	0.5	0.4	0.4	0.4	0.4	0.1
Calculated IV	53.1	56.0	56.8	59.6	56.0	52.2	59.1	55.1	2.9
Saturated, %	36.0	35.3	34.6	34.7	37.9	34.7	36.6	34.2	2.2
Monounsaturated, %	39.0	41.8	40.5	40.7	41.4	38.4	42.2	38.9	2.2
Polyunsaturated, % <sup>d</sup>	11.1	11.3	12.4	13.9	11.4	10.8	12.7	12.2	0.7
Mono:poly ratio <sup>c</sup>	3.6	3.8	3.4	3.0	3.7	3.6	3.8	3.3	0.2
U:S ratio <sup>dh</sup>	1.4	1.5	1.5	1.6	1.4	1.4	1.5	1.5	0.04

<sup>a</sup>Each mean represents 10 pens with three pigs per pen.  
<sup>b</sup>IV = iodine value of supplemented dietary fat.  
<sup>c</sup>Linear effect of diet ( $P < 0.01$ ).  
<sup>d</sup>Linear effect of diet ( $P < 0.001$ ).  
<sup>e</sup>Quadratic effect of diet ( $P < 0.001$ ).  
<sup>f</sup>Genotype  $\times$  gender  $\times$  diet interaction ( $P < 0.05$ ; see Figure 1).  
<sup>g</sup>Genotype  $\times$  gender interaction ( $P < 0.01$ ; see Table 10).  
<sup>h</sup>Genotype main effect ( $P < 0.05$ ).

(Morgan et al., 1994), representatives of Smithfield Foods and Oscar Mayer both noted that the consistency and composition of pork fat are quality concerns. Fat quality is also a problem around the world (Schworer et al., 1995). Swiss slaughterhouses have introduced a payment system that includes not only percentage lean, but also fat (IV) and meat (pH) quality measures.

Research has established (Seerley et al., 1978; Miller et al., 1990; Madsen, 1992) that the final fatty acid profile of pork carcass fat reflects the relative contribution of each dietary fat source. As more dietary fatty acids are deposited in the adipose tissue, de novo synthesis by the pig is decreased in relation to the amount contained in the diet. Therefore the type of fatty acids present in supplemental fat can impact the fat quality and fat firmness in resulting pork products. In addition, the IV is described as the amount of iodine (g) bound per 100 g of fat and is a measure of unsaturation because iodine reacts with the  $\pi$ -electrons of the double bonds. In previ-

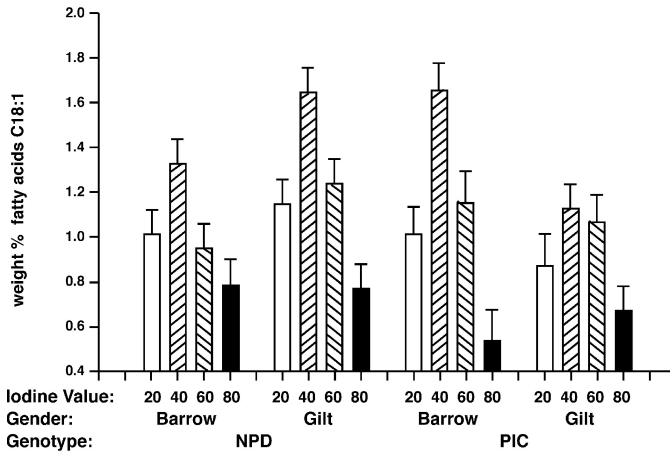
ous research, we examined the effects of tallow, animal-vegetable blended fat, soy oil, and hydrogenated animal fat (Averette Gatlin et al., 2002b). Because partially hydrogenated animal fat had a greater digestibility than blended fats of comparable IV (Averette et al., 1999), this experiment was designed to further evaluate the effects of partially hydrogenated fat on pork and fat quality and possible interactions with genotype and gender.

Genotype has been shown to affect growth rate and feed intake (Ellis and Augspurger, 2000). Lean growth rates also are affected by genotype and can subsequently affect pork quality. In this experiment, we did not detect any differences in feed intake, daily gain, or efficiency among the two genotypes selected. However, there were some differences in carcass weight, belly weight, fat depth, and carcass lean. In addition, these differences were not just due to genotype alone, but were dependent on gender. Gilts of the NPD genotype weighed less than all other groups throughout the trial even though they

**Table 10.** Effect of genotype and gender on C18:3 and polyunsaturated fatty acid content of the longissimus dorsi intramuscular fat of lean genotype pigs

Item, weight %	NPD		PIC		Pooled SEM
	Barrows	Gilts	Barrows	Gilts	
C18:3 <sup>a</sup>	0.3	0.5	0.5	0.4	0.1
Polyunsaturated <sup>b</sup>	10.9	13.4	11.4	12.2	0.5

<sup>a</sup>Genotype  $\times$  gender interaction ( $P < 0.01$ ).  
<sup>b</sup>Genotype  $\times$  gender interaction ( $P < 0.07$ ).



**Figure 1.** Effects of chemically hydrogenated dietary fats (iodine values of 20 to 80), gender (barrow vs. gilt) and genotype (NPD vs. PIC) on longissimus dorsi intramuscular fat content of C18:1*trans* fatty acid. Diet  $\times$  gender  $\times$  genotype interaction ( $P < 0.05$ ).

were of similar age. This is likely the reason for the observed differences in several carcass traits. Gender differences in performance traits have also been compared in many studies and summarized by Ellis and Augspurger (2000). The gender differences in fat depth and carcass lean as dietary saturated fat content increased are similar to those reported by Cline and Richert (2000). They note that barrows tend to consume more energy than gilts, so they store more of that energy as fat because they require less energy for lean accretion.

Increasing intramuscular fat can directly affect color by increasing reflectance (Karlsson et al., 1993). It appears that increasing saturation of supplemental fat reduced the color or redness of pork in this study. Intramuscular fat content tends to be lower in lean genotypes (Goerl et al., 1995). However, we did not determine the amount of intramuscular fat that may have confirmed those findings. Overall, the Minolta values and Japanese color scores were within acceptable ranges (National Pork Board, 2000).

Belly thickness is an important characteristic to consider when processing bacon. Thickness of bellies has been shown to have significant effects on raw, cured, and cooked weights (Brewer et al., 1995). In addition, sensory panelists observed a linear relationship between thickness and slice integrity, appearance, and lean:fat ratio of bacon (Brewer et al., 1995). Belly thickness (on both dorsal and ventral sides) was increased in our study as dietary supplemental fat saturation increased.

Most effects of lowering the IV of supplemental dietary fat were seen in the fatty acid composition of the carcass fat. Monounsaturated fatty acids increased in the belly, 10th-rib backfat, and intramuscular fat in relation to the amount of PUFA. Increasing concentrations of monounsaturated fatty acids in pork may have a positive effect on serum cholesterol concentrations in humans (Koch et al., 1968). More recently, monounsaturated

fatty acids have received favorable publicity in light of issues in human health related to blood lipid profiles and corresponding risk of cardiovascular disease (Mattson and Grundy, 1985; Grundy, 1986). Other recent research from our laboratory (Averette Gatlin et al., 2002a) showed that feeding conjugated linoleic acid (CLA) together with hydrogenated fat (i.e., tallow) further reduced the IV of carcass fat. Effects of CLA are presumably mediated via inhibition of steroyl-CoA desaturase activity (Smith et al., 2002) such that the content of monounsaturated fatty acids decreases while saturated fats correspondingly increase.

Suomi et al. (1993) evaluated several fat sources, including partially hydrogenated sunflower oil, and found a clear influence on the fatty acid profile of the adipose tissue of the pig. Linoleic acid content of the supplemental fats was negatively correlated to the firmness of the backfat ( $r = -0.83$ ). The C18:1*trans* content of the adipose tissue was 18.89% (wt/wt) after 88 d of consuming the partially hydrogenated sunflower oil diet. That is much greater than the C18:1*trans* content of adipose tissue in our study. However, the inclusion rate of the partially hydrogenated sunflower oil was 14.3% (wt/wt), and that oil contained 36% (wt/wt) C18:1*trans* compared to the IV 40 supplemental fat that contained 18.41% (wt/wt) C18:1*trans* in our study. In addition, the supplemental fat inclusion rate in our study was 5% and the highest incorporation of c18:1*trans* was seen in 10th-rib backfat samples at 2.71% (wt/wt) (Table 8). The lower inclusion rate used in our study did not result in any differences in feed intake or gain. However, Suomi et al. (1993) reported a significant reduction in gain and feed efficiency when the partially hydrogenated sunflower oil was fed ( $P < 0.05$ ).

Because pigs do not synthesize linoleic and linolenic acids, tissue content reflects the amount of those fatty acids present in the diet. In addition, linoleic acid has a greater impact on fat firmness compared to all other fatty acids (Berschauer, 1984). However, when PUFA such as linoleic acid are hydrogenated, the physical properties are altered and the resulting *cis* and *trans* positional isomers form an oil with a firmer structure (Emken, 1981). Other benefits include a reduction in rancidity and off flavors when compared to non-hydrogenated oils. There are some concerns for human health related to the intake of *trans* fatty acids. However, the small amount of C18:1*trans* seen in pork fat in this study would be minimal compared to the intake of *trans* fats present in other foods. Approximately 23% of the total *trans* fat intake in the United States is from margarine, whereas other major sources include baked goods and fried foods (Lichtenstein, 1995). Increased linoleic and elaidic acids were measured in backfat samples from pigs fed hydrogenated oil (Fontanillas et al., 1998). The quadratic response seen in our study likely resulted from an initial increase in *trans* double bonds in the hydrogenation process, with a decline as the process continued and further hydrogenated double bonds to create saturated fatty acids. Metabolic effects of *trans* fatty acids, if they are

incorporated into adipose tissue in swine, may resemble those of saturated fatty acids (Nestel et al., 1992). From these results, it can be concluded that hydrogenation is a viable method to reduce the linoleic acid content of a supplemental fat source to increase its value as an energy source when fat quality is a concern.

### Implications

Pork quality, especially that of the belly, is a combination of measures on a continuous scale that each have differing importance to processors and consumers. Pork belly quality, defined as reduced iodine value and increased belly thickness, can be improved by feeding fats with increased saturated fatty acid content. Supplemental fats with increased saturated fatty acid composition were not found to have an effect on growth rate, feed intake, or efficiency. Therefore, consideration should be given to feeding partially hydrogenated dietary fat during finishing to further enhance belly quality in lean genotype pigs while not adversely affecting growth performance.

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