

# The effects of the LIPEX finishing diet regimen on pork quality, fatty acid profile, palatability, and color stability<sup>1,2</sup>

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**ABSTRACT:** The objective of this study was to determine the effects of the LIPEX finishing diet regimen on pork chop n-3 polyunsaturated fatty acid (PUFA) content and fresh meat quality. Twenty-eight finishing pigs (PIC 359 × F1 Hermitage/NGT; initial BW 81.5 ± 2.55 kg) were subjected to a 49-d feeding trial. Treatments consisted of a 2 × 2 factorial design with Sex ( $n = 14$  barrows and gilts each) and Diet as main effects. Dietary treatments consisted of a 2-phase standard finishing diet regimen or a 2-phase LIPEX finishing diet regimen (EXL Milling, Lloydminster, SK, Canada). The LIPEX diet regimen added the EXL LIPEX.FA369 additive during phase 1 and the EXL LIPEX.FA369 and XFE Omega-3 Finishing Touch during phase 2. Five-days post-mortem, whole boneless pork loins were transported to the Kansas State University Meats Laboratory, aged 14 d, and halved immediately behind the spinalis dorsi. After blooming for 30 min, chops were evaluated for Japanese color score and National Pork Producers Council (NPPC) color and marbling scores. A 2.54-cm

chop was taken immediately anterior to the loin cut and was used for fatty acid and proximate composition analyses. Four 2.54-cm chops were cut from the posterior portion of the loin and were utilized for a 7-d simulated retail display analyses, Warner-Bratzler shear force (WBSF), and trained sensory panel. There were no Sex × Diet interactions for all variables measured in the study ( $P > 0.10$ ). The LIPEX finishing regimen increased chop C18:3n-3, C20:5, and C22:5, which decreased the n-6:n-3 ratio ( $P < 0.01$ ). There were no Diet effects on pH, Japanese and NPPC color and marbling scores, and proximate composition ( $P > 0.23$ ). Diet did not affect cook loss, WBSF, and trained sensory panel scores ( $P > 0.012$ ). There were no 2- or 3-way interactions between Diet, Sex, and Day, or Diet and Sex main effects for L\*a\* values, surface oxy- and metmyoglobin percentages, or visual panel chop redness and surface discoloration scores ( $P > 0.14$ ). Feeding the LIPEX finishing diet regimen increased chop n-3 PUFA content without negatively impacting fresh chop palatability or color stability.

**Key Words:** color, omega-3, palatability, pork, shelf-life

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## INTRODUCTION

The importance of n-3 polyunsaturated fatty acids (PUFA) in a healthy human diet has been known for decades. In the human body, alpha-linolenic acid (ALA) has been a major n-3 PUFA of importance because it is metabolized to eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). The dietary levels of n-3 PUFA in relation to n-6 PUFA (the omega-6:omega-3 ratio) are the key metric for determining the health of a diet (for reviews, see Simopoulos, 2000; Ma et al., 2016). In both humans and animal models studies and reviews demonstrated increased dietary n-3 PUFA decreased blood pressure (Miller et al., 2014), reduced the risk of obesity (Phillips et al., 2010; Simopoulos, 2016), enhanced brain development (Caspi et al., 2007), and intestinal development and function (Gabler et al., 2007). Based on studies such as these, dietary experts and some western consumers have focused identifying novel means to increase the n-3 PUFA content of their diet.

Historically, fish consumption was the primary means of increasing dietary n-3 PUFA; however, westerners, especially in the United States, consume low quantities of fish and Salem and Eggersdorfer (2015) concluded the oceans' supply of fish and aquaculture are inadequate to provide enough n-3 PUFA for optimal human nutrition. Therefore, livestock producers have studied novel means to manipulate the n-3 PUFA content of their protein products. Stephenson et al. (2016) demonstrated the ability of dietary components to alter the fatty acid composition of multiple fat depots within the pig. In the literature, a plethora of studies show dietary ingredients such as linseed/flaxseed and fish oil/meal increased meat n-3 PUFA content in various body adipose depots (Otten et al., 1993; Cherian and Sim, 1995; Juarez et al., 2010). While the increases reported in the literature are positive for the health of the consumer, many studies have reported major negative consequences to fresh meat palatability and color stability (Vatansever et al., 2000; Kouba et al., 2003; Phelps et al., 2016). Therefore, nutritionist have had to manage these issues when increasing the n-3 PUFA content of meat.

The LIPEX finishing diet regimen is a 2-step finishing diet designed to increase the n-3 PUFA content of pork while maintaining quality and color stability. This product is produced from a proprietary process that encapsulates n-3 PUFA extracted from partially digested whole flaxseeds. This process, in turn, makes the n-3 PUFA more bioavailable in the formulated diet. To date, no

studies have confirmed the ability of this feeding regimen to increase PUFA content while sparing the negative palatability and color stability effects commonly reported. Therefore, the objective of this study was to examine the effect of the LIPEX feeding regimen on pork chop fatty acid composition, color stability, and palatability.

## MATERIALS AND METHODS

### *Live Animal Management*

The study protocol was reviewed and approved by the Institutional Animal Care and Use Committee of Midwest Veterinary Services.

During the finishing phase, pigs ( $n = 14$  gilts and  $n = 14$  barrows; PIC 359  $\times$  F1 Hermitage/NGT; initial BW  $81.5 \pm 2.55$  kg) were assigned to pens so there were 2 pigs, with a gilt and barrow, in each pen. Study pens were located within a building that utilized negative pressure fans to circulate air and control temperature. Pens measured  $1.5 \times 2.1$  m, had plastic coated flooring, and contained feeders and waterers that allowed pigs ad libitum access to feed and water. Pens were randomly assigned to 1 of 2 dietary treatments of either a standard 2-stage commercial finishing diet or a diet consisting of the 2-stage LIPEX finishing diet regimen (EXL Milling, Lloydminster, SK, Canada; Table 1). Phase 1 and 2 diets were fed from day 0 to 20 and day 21 to 49 of finishing, respectively.

### *Harvest and Loin Processing*

On day 49 of feeding, pigs were transported and harvested at a Federally Inspected abattoir (Sioux-Preme Packing Co., Sioux Center, IA). Five-days postmortem, whole boneless pork loins (Institutional Meat Purchasing Specifications #413) were fabricated, vacuum packaged, and transported to the Kansas State University Meats Laboratory for analyses. Loins were aged 14-d postmortem and cut perpendicularly to the longitudinal axis of the loin, immediately behind the spinalis dorsi. Loins bloomed for 30 min and a trained university individual collected pH (model HI 99163; Hannah Instruments, Smithfield, RI) and subjective visual color data including Japanese color score (Nakai et al., 1975) and National Pork Producers Council (NPPC) color and marbling scores (NPPC, 1999). A 2.54-cm chop was cut immediately anterior to cut that halved the loin and was used for proximate and fatty acid analyses and four 1-inch chops were cut toward the posterior

**Table 1.** Diet compositions (as-fed basis)<sup>1</sup>

Item	Control		LIPEX	
	Phase 1	Phase 2	Phase 1	Phase 2
Ingredient, %				
Corn	67.35	77.75	74.30	74.10
Soybean meal, 47% CP	9.00	8.75	15.00	15.00
DDG with solubles	20.00	10.00	–	–
Dicalcium, 21%	0.25	0.25	0.50	0.50
Limestone	1.15	1.05	1.05	0.95
Salt	0.50	0.50	0.50	0.50
L-Lys HCl	0.35	0.30	0.20	0.25
DL-Met	–	–	0.05	0.05
XFE 4996 G/F Premix with phytase <sup>2</sup>	0.40	0.40	0.40	0.40
Liquid animal fat	1.00	1.00	–	–
Liquid energy 2X <sup>3</sup>	–	–	0.50	0.50
EXL LIPEX.FA369 <sup>4</sup>	–	–	7.50	7.50
XFE Omega 3 Finishing Touch <sup>5</sup>	–	–	–	0.25
Total	100.00	100.00	100.00	100.00

<sup>1</sup>Phase 1 and 2 diets were fed in meal from day 0 to 20 and day 21 to 49, respectively.

<sup>2</sup>Vitamin and trace mineral supplement containing 2.2% zinc, 75 ppb selenium, 881,057 IU/kg vitamin A, 550,660 IU/kg vitamin D<sub>3</sub>, and 8,810 IU/kg vitamin E (XFE Products, Des Moines, IA).

<sup>3</sup>Liquid energy 2X (XFE Products, Des Moines, IA) analyzed to contain 7% CP, 1% crude fat, 0.75% crude fiber, 1.4% phosphorus, 12.5% salt, and 30 ppm zinc.

<sup>4</sup>EXL LIPEX.FA369 (XFE Products, Des Moines, IA) produced from partially digested whole flaxseeds, partially digested whole canola seeds, canola meal, and field peas. Analyzed to contain (as-fed) 20% protein, 41% crude fat, and 7% crude fiber.

<sup>5</sup>XFE Omega 3 Finishing Touch (XFE Products, Des Moines, IA) analyzed to contain (as-fed) 8% calcium and 13.80 IU/kg of vitamin E.

portion of the loin. The first chop was utilized for 7-day simulated retail display analyses, the second chop for Warner-Bratzler shear force (WBSF), and the last 2 chops for trained sensory panel. Trained sensory panel chops were vacuum packaged and stored at –20 °C until analysis, while WBSF chops immediately went to cooking

### Proximate and Fatty Acid Analyses

The subcutaneous fat and spinalis dorsi muscle from the chop designated for laboratory analyses were removed, and the longissimus lumborum muscle was chopped into cubes, submerged in liquid nitrogen, and pulverized in a Waring blender (Waring Products, New Hartford, CT). Powdered sample was transferred to Whirl-Pac bags (Nasco, Fort Atkinson, WI) and stored at –80 °C until analyses.

Protein content was determined by analyzing the nitrogen content of 0.5 g of sample using the

combustion method of a Leco nitrogen analyzer (AOAC Official Method 990.03; TruMac N, Leco Corp., St. Joseph, MI). Nitrogen values were multiplied by 6.25 to calculate protein content. Moisture and fat were determined following the AOAC Official Method PVM-1:2003 using the microwave and NMR functions of a CEM SmarTrac System (CEM Corporation, Mathews, NC).

### Fatty Acid Analysis

The fatty acid profiles of the 3 g of ground muscle samples were determined by gas chromatography (Shimadzu, model 14 A, Tokyo, Japan) with a flame ionization detector, as described previously (Cromwell et al., 2011). Samples were transmethylated according to the methods of Park and Goins (1994) and 2 mg of tridecanoic acid (C13:0) was added as an internal standard before processing. Methyl esters were isolated in hexane, anhydrous sodium sulfate was added to remove any residual water, and samples were stored at 4 °C until analyzed.

Fatty acid methyl esters were separated on a Phenomenex, ZBWax Plus wide-bore capillary column (60 m × 0.53 mm, 1.00 µm film thickness; Phenomenex, Torrance, CA) with nitrogen as the carrier gas. Initial column temperature was 160 °C, temperature was held for 10 min and increased at a rate of 5 °C/min until 220 °C. Injector temperature was 250 °C and detector temperature was 260 °C. Peaks were identified by comparison of retention times of known standards (Nu-Chek Prep, Elysian, MN).

### Warner-Bratzler Shear Force and Trained Sensory Panel

Warner-Bratzler shear force and trained sensory panel procedures followed the methods outlined in the American Meat Science Association's (AMSA) Research Guidelines for Cookery, Sensory Evaluation, and Instrumental Tenderness Measurements of Meat (AMSA, 2016). After cutting, chops were weighed, a thermocouple wire was inserted into the geometric center of each chop (30-gauge copper and constantan; Omega Engineering, Stamford, CT), and chops were cooked using a clamshell-style grill (Griddler; Cuisinart, Stamford, CT). Internal temperatures were measured using a Doric Minitrend 205 (VAS Engineering, San Francisco, CA) and steaks were pulled from the grill at approximately 65 °C to reach a resting

temperature of 71 °C. Chops were reweighed and drip loss was calculated as [(precooked weight – cooked weight)/precooked weight] × 100. Chops were placed on trays, covered with polyvinylchloride film, and chilled over night at 4 °C. Six 1.27-cm diameter cores were removed from the chop parallel to the orientation of the muscle fibers and sheared once through the center using a Warner-Bratzler shear head attached to an INSTRON Universal Testing Machine (100 kg compression load cell and a crosshead speed of 250 mm/min; Model 5569; Instron, Canton, MA).

The KSU Institutional Review Board approved all procedures for use of human subjects in the trained sensory panel evaluations (IRB #7440.5, September 2018). Trained panelists were oriented to evaluating pork chop palatability over 5 training sessions prior to data collection. Details regarding the anchors and training procedures used are outlined by Rice (2019). Chops used for trained sensory analysis were thawed overnight at 4 °C and cooked as described above. Following cooking and a brief rest period, chops were cut into 1.27 × 1.27 × 2.54-cm samples and 2 cubes for 8 samples were served to 8 panelists sitting in individual booths that had red and green lighting illuminating the samples. Panelists evaluated samples on 100-point continuous line scales with anchors at both ends and in the middle. Attributes and anchors were initial/sustained juiciness: 0 = extremely dry, 50 = neither dry/juicy, 100 = extremely juicy; myofibrillar/overall tenderness: 0 = extremely tough, 50 = neither tough/tender, 100 = extremely tender; connective tissue amount: 0 = none, 100 = abundant; pork flavor/off flavor intensity: 0 = extremely bland, 100 = extremely intense. Panelists recorded their ratings on handheld tablets (Hewlett-Packard) that were running Qualtrics Survey Software (Qualtrics, Seattle, WA).

### *Simulated Retail Display*

Chops used for retail display were placed on Ultra Zap absorbent pads (Paper-Pak Industries Inc., Washington, GA), then place on 1S Styrofoam trays, and overwrapped with polyvinylchloride film that possessed an oxygen transmission rate of 1,450 cm<sup>-3</sup>·645.2 cm<sup>-2</sup>·24 h<sup>-1</sup> (AEP Industries Inc., South Hackensack, NJ). Chops were placed on the tray with the posterior portion of the chop facing up. Chops were placed in a coffin-style retail case (Model DMF 8; Tyler Refrigeration Corporation, Niles, MI) operating at 3 ± 2 °C and set to defrost twice a day (morning and evening) at 11 °C

for 30 min. Cases were constantly illuminated with warm fluorescent light (32 W Del-Warm White 3000 °K; Philips Lighting Company, Somerset, NJ) that emitted a case average of 2,112 ± 103 lx and case temperatures were monitored with 3 ThermoChon iButtons (Maxim Integrated Products, Sunnyvale, CA) placed evenly throughout the case. Chops were rotated twice a day (morning and evening) from left to right and front to back to account for lighting and temperature variation throughout the case.

Once daily for 7 d, objective and subjective color measurements were taken. Objective measures were taken on 2 locations of each chop by a Miniscan EZ spectrophotometer (Illuminant A, 2.54-cm diameter aperture, 10° observer; Hunter Associates Laboratory, Reston, VA). Reflectance readings of CIE L\*, a\*, b\*, and at 400 to 700 nm were averaged for the 2 readings to determine a chop average. Readings at 473, 525, 572, and 700 nm were used to calculate surface oxy- and metmyoglobin percentage according to the equations published in the AMSA Meat Color Measurement Guidelines (AMSA, 2012).

Eight to ten visual panelists were tested for color blindness using the Farnsworth-Munsell 100 HueColor Vision Test and oriented in a series of 3 training sessions prior to the start of the study to 100-point continuous line scales for chop redness and percent surface discoloration. The redness scale was based on the NPPC color standards with 0 = 1.0 (pale pinkish gray to white), 50 = 3.5 (between reddish pink and dark reddish pink), and 100 = 6.0 (dark purplish red). Anchors for percent surface discoloration were 0 = 0% discoloration, 50 = 50% discoloration, and 100 = 100% discoloration. Panelists recorded their scores electronically on handheld tablets (HP Steam 7 tablets 5709; Hewlett Packard, Palo Alto, CA) running Qualtrics Survey Software (Qualtrics). Data were downloaded daily and all ratings were averaged to a daily chop average.

### *Statistical Analyses*

Data including pH, 14-d subjective loin color, proximate composition measures, fatty acid composition measures, WBSF, and trained sensory panel measures were analyzed as a completely randomized design with a 2 × 2 factorial arrangement with pig as the experimental unit. Fixed effects included Diet and Sex. Objective and subjective color data were analyzed as a completely randomized design with a 2 × 2 factorial arrangement with repeated measures. Day served as the repeated measure with chop as the



subject and autoregressive as the covariance structure. Data were analyzed using the PROC MIXED procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC) and pairwise comparisons between the least squares means were computed using the PDIFF option of the LSMEANS statement. Differences were considered significant at  $P \leq 0.05$ . Tendencies were noted at  $P > 0.05$  and  $\leq 0.10$ .

## RESULTS

For all variables measured, there were no significant Diet  $\times$  Sex interactions ( $P > 0.10$ ). There were tendencies for there to be a Diet  $\times$  Sex interaction for the amount of C16:0 and C20:2 ( $P = 0.08$ ; Table 2). Control gilts had less ( $P < 0.01$ ) C16:0 than barrows, but the sexes did not differ ( $P = 0.18$ ) when the LIPEX feeding regimen was employed. Pigs fed the LIPEX feeding regimen had more C18:3n3, C20:5,

and C22:5 than pigs fed the control diet ( $P < 0.01$ ). This resulted in pigs fed the LIPEX diet having a reduced ( $P < 0.01$ ) omega-6:omega-3 ratio. Sex did affect the fatty acid profile of the intramuscular fat of the longissimus muscle (LM). Barrows had more C12:0, C14:0, C16:0, C16:1, C18:1, C20:0, and C20:1 than gilts ( $P < 0.05$ ). Gilts had more C14:1, C17:1, C18:2, C18:3n3, C20:3, C20:4, and C22:4 than barrows ( $P < 0.05$ ). These results caused gilts to have more saturated fatty acids and polyunsaturated fatty acids, and less monounsaturated fatty acids than barrows ( $P < 0.02$ ).

Dietary treatment did not affect ultimate pH, subjective color scores, or proximate composition of the LM ( $P > 0.23$ ; Table 3). Sex did not affect most LM measures ( $P > 0.24$ ) except barrows had greater ( $P = 0.01$ ) NPPC marbling scores than gilts. Barrows also tended to have greater Japanese color scores and more fat than gilts ( $P = 0.07$ ).

**Table 2.** Effect of the LIPEX finishing diet regimen and sex on longissimus muscle fatty acid profile

Fatty acid methyl ester <sup>1</sup>	Barrow		Gilt		SEM	P-value		
	Control	LIPEX	Control	LIPEX		Diet $\times$ Sex	Diet	Sex
10:0	0.113	0.113	0.100	0.090	0.012	0.75	0.74	0.11
12:0	0.096	0.087	0.076	0.073	0.006	0.65	0.36	0.01
14:0	1.768	1.679	1.590	1.544	0.047	0.64	0.17	<0.01
14:1	0.172	0.204	0.240	0.286	0.036	0.85	0.29	0.05
15:0	0.137	0.143	0.168	0.171	0.015	0.95	0.78	0.07
16:0	24.278	23.655	22.368	22.989	0.337	0.08	1.00	<0.01
16:1	3.873	3.770	3.513	3.098	0.167	0.36	0.13	0.01
17:0	0.545	0.599	0.680	0.611	0.068	0.37	0.92	0.29
17:1	0.707	0.740	0.882	0.804	0.058	0.35	0.71	0.05
18:0	11.244	11.183	11.338	11.703	0.353	0.55	0.67	0.39
18:1	40.448	39.651	37.546	36.790	1.271	0.99	0.55	0.03
18:2	11.734	12.469	15.135	14.966	1.135	0.69	0.81	0.02
18:3n3	0.302	0.699	0.396	0.981	0.081	0.26	<0.01	0.03
20:0	0.122	0.122	0.107	0.095	0.010	0.57	0.55	0.04
20:1	0.707	0.712	0.607	0.621	0.046	0.92	0.85	0.05
20:2	0.413	0.492	0.501	0.438	0.039	0.08	0.83	0.67
20:3	0.262	0.263	0.381	0.364	0.034	0.80	0.82	<0.01
20:4	2.171	2.554	3.453	3.430	0.421	0.63	0.67	0.02
20:5	0.016	0.088	0.023	0.156	0.023	0.19	<0.01	0.11
22:2	0.574	0.449	0.433	0.360	0.088	0.77	0.27	0.20
22:4	0.318	0.329	0.467	0.430	0.053	0.66	0.81	0.03
22:5	0.050	0.213	0.120	0.302	0.051	0.85	<0.01	0.13
Total SFA <sup>2</sup>	27.766	25.967	27.138	27.378	0.355	0.16	0.76	<0.01
Total MUFA <sup>3</sup>	45.907	42.788	45.077	41.599	1.374	0.90	0.47	0.02
Total PUFA <sup>4</sup>	15.840	20.908	17.555	21.427	1.660	0.72	0.51	0.01
Omega-6:omega-3 ratio <sup>5</sup>	28.79	13.07	35.18	10.49	3.69	0.24	<0.01	0.61

<sup>1</sup>Milligram per gram wet tissue.

<sup>2</sup>SFA = saturated fatty acid. Total SFA = 10:0 + 12:0 + 14:0 + 15:0 + 16:0 + 17:0 + 18:0 + 20:0.

<sup>3</sup>MUFA = monounsaturated fatty acid. Total MUFA = 14:1 + 16:1 + 17:1 + 18:1 + 20:1.

<sup>4</sup>PUFA = polyunsaturated fatty acid. Total PUFA = 18:2 + 18:3n3 + 20:2 + 20:3 + 20:4 + 20:5 + 22:2 + 22:4 + 22:5.

<sup>5</sup>Ratio = 18:2/(18:3n3 + 20:5 + 22:5).

**Table 3.** Effect of feeding a LIPEX finishing diet regimen on longissimus muscle pH, subjective color scores, and proximate composition

Item	Barrow		Gilt		SEM	P-value		
	Control	LIPEX	Control	LIPEX		Diet × Sex	Diet	Sex
pH	5.61	5.59	5.58	5.50	0.05	0.50	0.26	0.23
Color scores								
Japanese color <sup>1</sup>	3.5	3.2	3.1	2.9	0.2	0.86	0.23	0.07
NPPC color <sup>2</sup>	3.4	3.1	3.0	3.0	0.2	0.56	0.56	0.24
NPPC marbling <sup>3</sup>	3.2	2.3	1.7	1.8	0.4	0.20	0.27	0.01
Proximate analysis <sup>4</sup> , %								
Protein	23.0	22.7	23.0	23.1	0.2	0.28	0.65	0.32
Moisture	73.9	74.0	73.8	74.0	0.3	0.86	0.69	0.86
Fat	3.2	2.4	2.2	2.0	0.4	0.43	0.20	0.07

<sup>1</sup>Japanese pork color standards based on a 6-point scale (1 = pale grey, 6 = dark purple; Nakai et al., 1975).

<sup>2</sup>NPPC = National Pork Producers Council. Color scale based on a 6-point scale (1 = pale pinkish gray to white, 6 = dark purplish red; NPPC, 1999).

<sup>3</sup>Marbling scale based on 10-point scale (1 = 1% intramuscular fat content, 10 = 10% intramuscular fat content).

<sup>4</sup>Proximate composition was measured on longissimus muscle only.

**Table 4.** Effect of feeding a LIPEX finishing diet regimen on loin chop cook loss, Warner-Bratzler shear force, and trained sensory panel scores

Item	Barrow		Gilt		SEM	P-value		
	Control	LIPEX	Control	LIPEX		Diet × Sex	Diet	Sex
Objective measures								
Cook loss <sup>1</sup> , %	16.95	17.32	18.07	18.69	0.74	0.87	0.51	0.11
WBSF <sup>2</sup> , kg	2.14	2.36	2.38	2.41	0.11	0.65	0.63	0.36
Trained sensory panel measures <sup>3</sup>								
Initial juiciness	54.2	49.5	48.7	47.0	4.4	0.74	0.47	0.37
Sustained juiciness	42.5	37.7	37.2	35.7	4.6	0.73	0.50	0.43
Myofibrillar tenderness	71.4	65.7	64.8	62.3	3.3	0.62	0.22	0.14
Connective tissue	1.8	3.0	6.0	4.1	0.9	0.10	0.66	<0.01
Overall tenderness	70.8	65.4	62.4	61.5	3.3	0.50	0.35	0.08
Pork flavor	39.3	37.7	37.4	35.9	1.0	0.97	0.12	0.07
Off flavor intensity	4.1	6.0	9.6	7.5	3.5	0.56	0.97	0.33

<sup>1</sup>[(precooked weight – cooked weight)/precooked weight] × 100.

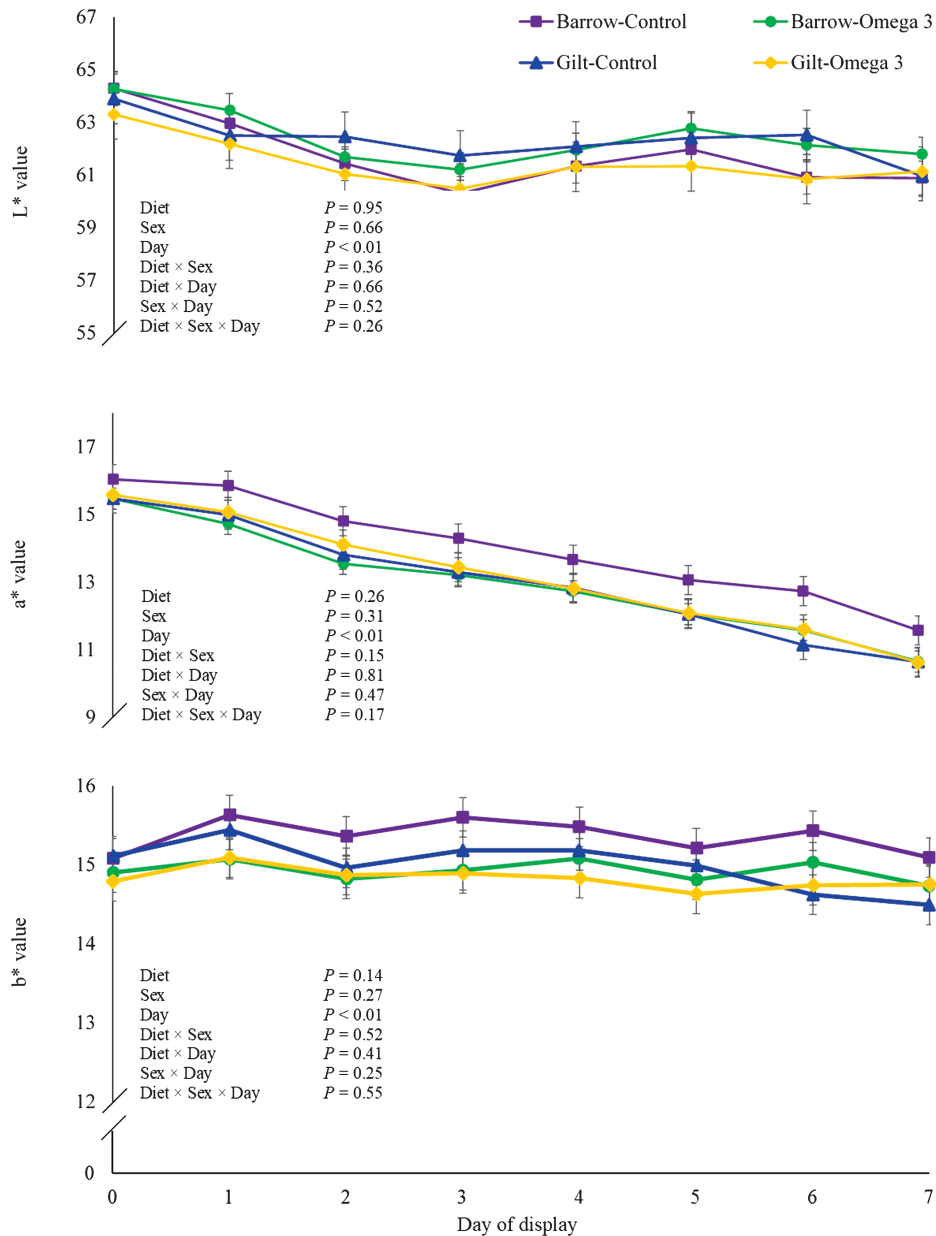
<sup>2</sup>WBSF = Warner-Bratzler shear force.

<sup>3</sup>Initial/sustained juiciness: 0 = extremely dry, 50 = neither dry/juicy, 100 = extremely juicy; myofibrillar/overall tenderness: 0 = extremely tough, 50 = neither tough/tender, 100 = extremely tender; connective tissue amount: 0 = none, 100 = abundant; pork flavor/off flavor intensity: 0 = extremely bland, 100 = extremely intense.

Diet did not impact cook loss, WBSF, or trained sensory panel scores ( $P > 0.11$ ; Table 4). Trained panelists detected gilt chops had more ( $P < 0.01$ ) connective tissue and tended to have less overall tenderness and pork flavor ratings than barrows ( $P < 0.08$ ).

There were no 3-way or 2-way interactions for all objective and subjective chop color measures ( $P > 0.15$ ; Figs. 1–3), except there were Sex × Day and Diet × Sex interactions for visual panel redness and percent surface discoloration scores, respectively. When sexes were compared within day of display for redness scores, there were no differences in

visual panel scores ( $P > 0.10$ ). Therefore, the interaction lied in the rate of redness decline with gilts having a faster decline in redness scores compared to barrows. The Diet × Sex interaction occurred due to visual panelists rating control gilt chops as having more ( $P = 0.02$ ) discoloration than barrows during the 7-d display period, while there was no difference ( $P = 0.67$ ) between the chops of sexes fed the LIPEX feeding regimen. Finally, there were significant Day effects for all objective and subjective color measures ( $P < 0.01$ ), which were typical for the discoloration patterns seen during simulated retail display.



**Figure 1.** Effect of feeding the LIPEX finishing diet regimen on longissimus muscle L\*a\*b\*. Pigs ( $n = 14$  barrows and 14 gilts) were subjected to a 2-phase control or LIPEX finishing regimen during the last 49 d of feeding. After 10 d of aging, chops were fabricated and subjected to 7-d simulated retail display.

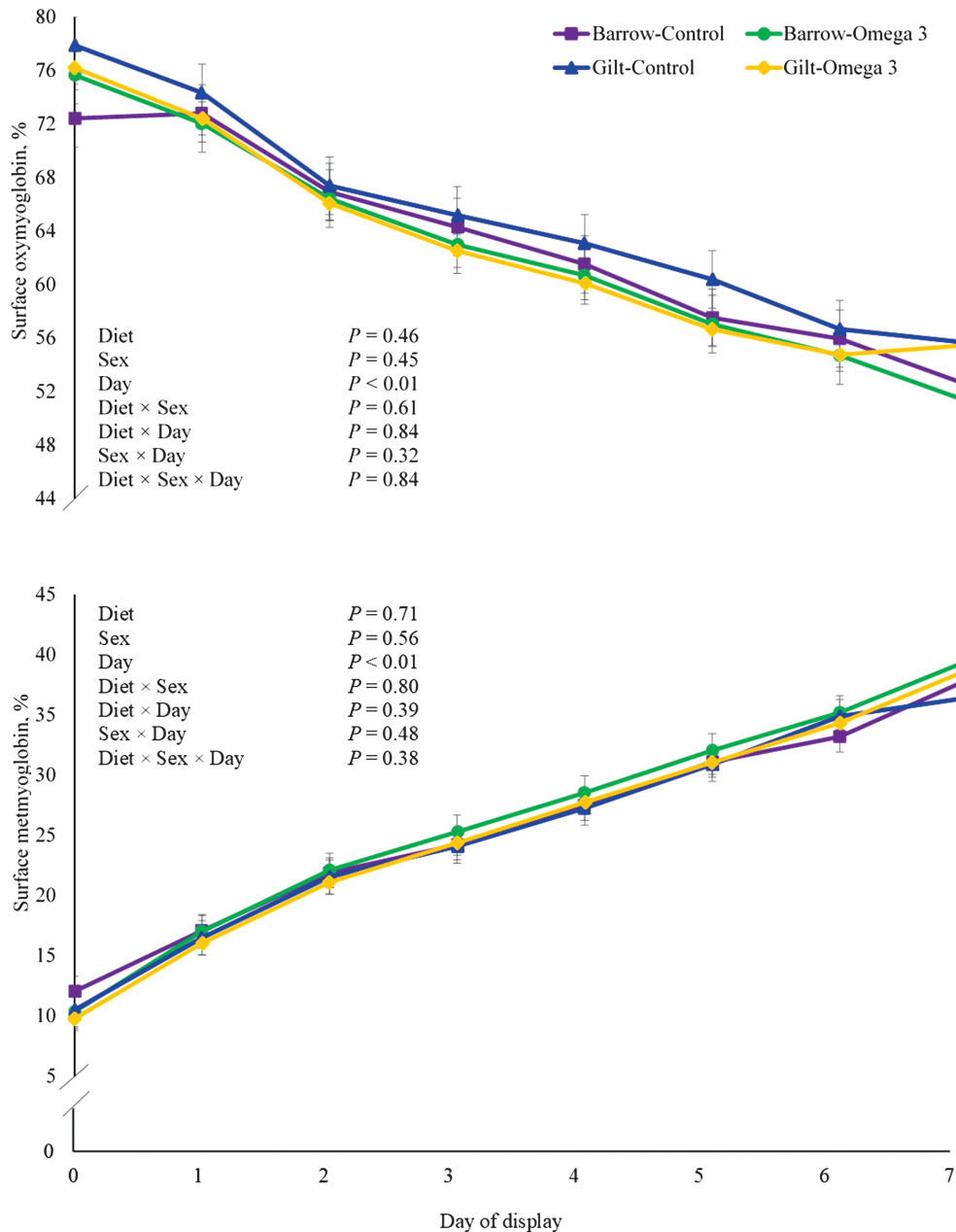
## DISCUSSION

### Sex Effects

Surprisingly, few studies have specifically focused on the effect of sex on objective and subjective meat quality measurements. Several studies found the fatty acid profile of barrows and gilts differ when analyzed among different breeds and fat depots (Warnants et al., 1999; Ramirez and Cava, 2007; Zhang et al., 2008). Juarez et al. (2011) found barrows deposited n-3 PUFA at a greater rate than gilts when they were fed increasing levels of flaxseed. Zhang et al. (2007) reported barrows had

more C14:0, C16:0, C16:1, and C18:1, while gilts had more C18:2 and C20:4. Ntawubizi et al. (2009) reported gilts had more C18:2, C20:3, C20:4, and C22:4 than barrows. The authors further concluded that these findings may be due to the indirect effect of barrows having more fat than gilts. This was also seen in the current study as described by the marbling scores and fat analysis presented below.

The results of the current study indicate barrows had almost 1 point greater visual marbling score than gilts, which corresponded to a 0.7% in fat detected by proximate analysis. Arkfeld et al. (2017) reported sex accounted for 15.8% of the



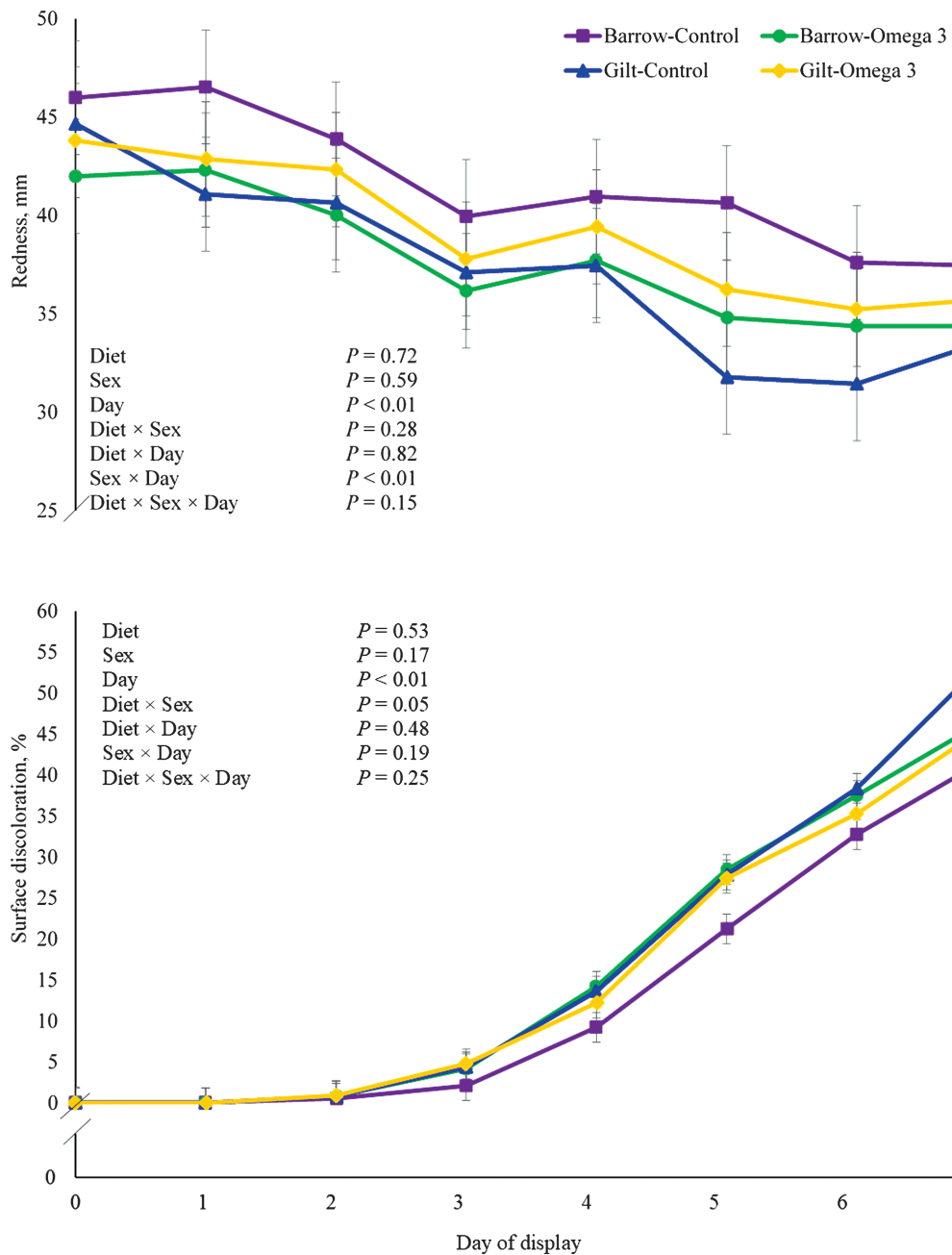
**Figure 2.** Effect of feeding the LIPEX finishing diet regimen on longissimus muscle surface oxy- and metmyoglobin accumulation. Pigs ( $n = 14$  barrows and 14 gilts) were subjected to a 2-phase control or LIPEX finishing regimen during the last 49 d of feeding. After 10 d of aging, chops were fabricated and subjected to 7-d simulated retail display. Chop surface oxy- and metmyoglobin percentages were calculated using readings at 473, 525, 572, and 700 nm and according to the equations published in the American Meat Science Association's (AMSA) Meat Color Measurement Guidelines (AMSA, 2012).

variation in carcass leanness. Additionally, this group also noted barrows had 0.49-point increase in NPPC marbling scores when compared to gilts (Overholt et al., 2016). While Boler et al. (2014) found sex only influenced pH measures and not marbling or color scores, Elsbernd et al. (2016) reported physically castrated males had NPPC marbling scores that were 0.50 point greater than gilts. In agreement with the current study, both Overholt et al. (2016) and Elsbernd et al. (2016) reported no sex influence on NPPC or Japanese color scores,

respectively. Therefore, the sex effect on marbling scores and fat content found in the current study are to be expected.

Huff-Lonergan et al. (2002) established marbling was correlated to both subjective and objective pork palatability measures. Drey et al. (2019) demonstrated the effect marbling has on improved consumer and trained panel tenderness, juiciness, and flavor ratings. Juarez et al. (2011) found pork chops from barrows were 1.2 points greater in flavor than gilts. Overholt et al. (2016) reported gilts had 0.16 kg





**Figure 3.** Effect of feeding the LIPEX finishing diet regimen on longissimus muscle visual color panel redness and surface discoloration scores. Pigs ( $n = 14$  barrows and 14 gilts) were subjected to a 2-phase control or LIPEX finishing regimen during the last 49 d of feeding. After 10 d of aging, chops were fabricated and subjected to 7-d simulated retail display. Redness scale was based on the NPPC color standards with 0 = 1.0 (pale pinkish gray to white), 50 = 3.5 (between reddish pink and dark reddish pink), and 100 = 6.0 (dark purplish red). Percent surface discoloration anchors were 0 = 0% discoloration, 50 = 50% discoloration, and 100 = 100% discoloration.

greater slice-shear force values than barrows which agrees with several other studies (Nold et al., 1997; D'Souza and Mullan, 2002). No Sex effect was seen in the current study for WBSF; however, trained panelists did detect more connective tissue in gilt chops which resulted in decreased overall tenderness. Additionally, panelists also detected less pork flavor in gilt chops which was most likely due to the reduced marbling and fat content of the meat.

Commonly, there are no differences in chop color reported between genders (Boler et al., 2014;

Elsbernd et al., 2016). Overholt et al. (2016) reported, at most, one-half point differences in  $L^*a^*b^*$  values between barrows and gilts which the authors stated are most likely not detectable by the human eye. To date no data document chop discoloration patterns according to gender. In the current study, most objective and subjective color measurements indicated no difference in barrow and gilt chop color stability. Panelists' ratings indicated gilt chops became pale at a quicker rate than barrows, especially at day 5 and 6 of the display period. It

is unknown why this occurred, but it is hypothesized this could have occurred due to the level of precision (100 point) of the scale utilized to rate the chops, as opposed to 8- or 9-point scales commonly used in published literature. Panelists also indicated the genders differed in color stability within the control treatment, but did not differ when subjected to the LIPEX regimen. This could be due to the elevated vitamin E in the LIPEX feeding regimen, as [Sales and Koukolova \(2011\)](#) estimated elevated vitamin E concentration in the muscle 2.7 µg/g of meat was needed to maximize a\* value during 8 to 13 d of refrigerated display.

### *Diet Effects*

Currently in the meat case there is a niche market for selling more healthful meat to consumers. One portion of this market are those meat products fortified in n-3 PUFA. As mentioned previously, producers have interest in improving the nutritive value of meat because of the wealth of data which indicated diets elevated in n-3 PUFA elicit many health advantages (for review, see [Calder, 2018](#)). Therefore, for decades livestock producers have employed numerous strategies to manipulate the n-3 PUFA content of their products. In the current study, the LIPEX feeding regimen is a 2-step finishing dietary regimen that has encapsulated n-3 PUFA which are extracted from flaxseed using a proprietary process. Meat harvested from barrows and gilts fed this diet had increased LM 18:3n3, C20:5, and C22:5, all PUFA. In turn, this resulted in a reduction of the n-6:n-3 ratio by 63%. The C22:6 PUFA was not detectable in the current study which may indicate this fatty acid was unaffected by the LIPEX feeding regimen and remained at levels that were undetectable. [Romans et al. \(1995a\)](#) found including 0, 10, and 15% flaxseed in finishing diets for 25 d increased longissimus C18:3 and C20:5 a maximum of 358 and 67%, respectively, with no effect on C22:6. In a follow-up study, [Romans et al. \(1995b\)](#) reported supplementing 15% flaxseed for up to 28 d increased C18:3 by 162% and C20:5 by 191% and once again had no effect on C22:6. [Kouba et al. \(2003\)](#) also found dietary crushed linseed did not affect longissimus C22:6 content but slowed the rate of decline for C18:3n-3 and C22:5n-3 during a 100-d feeding period. The authors also reported after 20 d of feeding the n-6:n-3 ration fell 63%. When investigating linseed oil supplementation during finishing, [Haak et al. \(2008\)](#) reported C18:3n-3 and 20:5:n-3 increased, while C:22:6n-3

was unaffected. Additionally and in agreement with the current study, the authors also reported C22:5n-3 increased 60% and the n-6:n-3 ratio decreased 77%. Therefore, the response in the current study is similar to what was reported historically.

Color is one of the most important attributes consumers use in the retail meat purchasing decision and a positive palatability experience ensures the consumer will continue to buy a product. Therefore, novel feeding regimens must not negatively alter these 2 attributes if it is going to gain acceptance in the industry. When focusing on manipulating the n-3 PUFA content of meat, drastic elevation in n-3 PUFA content can have a negative effect on both fresh meat color and palatability ([Phelps et al., 2016](#)). [Romans et al. \(1995b\)](#) reported a high fat product, such as bacon, had greater sensory panel off-flavor scores when pigs were fed flaxseed. [Kouba et al. \(2003\)](#) found dietary linseed increased objective tenderness by 19% and pork chop flavor liking decreased by 8%. [Juarez et al. \(2011\)](#) reported increasing levels of dietary flaxseed decreased pork flavor intensity and simultaneously increased off-flavor intensity. The authors also found flaxseed decreased L\* values which may have been a result of greater pH values. [Jiang et al. \(2017\)](#) also reported linseed oil supplementation caused reduced L\* and/or a\* values through day 4 of refrigerated storage. Therefore, the increased n-3 PUFA content of the current study could have resulted in reduced color stability and palatability characteristics.

In the current study, dietary treatment did not affect all color and palatability measures. Several other studies indicated increased n-3 PUFA content did not result in increased off-flavor or a reduction in pork flavor ([Romans et al., 1995a](#); [Van Oeckel et al., 1996](#)). While [Haak et al. \(2008\)](#) noted color was unaffected by dietary linseed incorporation, the authors speculated this was mainly due to the inclusion level being well below what would negatively affect meat color. [Kouba et al. \(2003\)](#) found color saturation values did not differ for chops from pigs fed crushed linseed during 7 d of retail display. The reason for the lack of color difference in this study could be due to the muscle from linseed chops possessing more vitamin E than control chops despite the diets including the same amount of vitamin E. In pork models, several studies demonstrated dietary vitamin E improved color stability and reduced TBARS formation, a compound associated with lipid oxidation, color stability, and off-flavor development ([Asghar et al., 1991](#); [Waylan](#)

et al., 2002, Guo et al., 2006). While many studies indicated vitamin E does not affect color stability (Phillips et al., 2001; Boler et al., 2009), vitamin E improved color stability when color-affecting feed-stuffs such as dried distillers grains with solubles are fed (Wang et al., 2012). Therefore, because the XFE Omega 3 Finishing Touch product fed during phase 2 of finishing contained supplemental vitamin E, this may be the reason there were no differences in color and palatability measures in the current study.

## CONCLUSION

Feeding the LIPEX finishing diet regimen to finishing barrows and gilts increased the LM concentration of all important n-3 PUFA except C22:6. These increases in n-3 PUFA resulted in a decrease in the n-6:n-3 ratio. There was no negative effect on palatability and color measures commonly seen with increased n-3 PUFA content. This was most likely due to the evaluated vitamin E content of the phase 2 portion of the LIPEX feeding regimen. Thus, the LIPEX finishing diet regimen is a viable feeding strategy producers can employ to increase the n-3 PUFA content of the meat without any negative fresh meat quality effects.

## LITERATURE CITED

- American Meat Science Association. 2012. Meat color measurement guidelines. 2nd ed. American Meat Science Association, Champaign, IL.
- American Meat Science Association. 2016. Research guidelines for cookery, sensory evaluation and instrumental tenderness measurements of fresh meat. 2nd ed. American Meat Science Association, Champaign, IL.
- Arkfeld, E. K., D. A. Mohrhauser, D. A. King, T. L. Wheeler, A. C. Dilger, S. D. Shackelford, and D. D. Boler. 2017. Characterization of variability in pork carcass composition and primal quality. *J. Anim. Sci.* 95:697–708. doi:10.2527/jas.2016.1097
- Asghar, A., J. I. Gray, A. M. Booren, E. A. Gomaa, M. M. Abouzid, E. R. Miller, and D. J. Buckley. 1991. Effects of supranutritional dietary vitamin E levels on subcellular deposition of  $\alpha$ -tocopherol in the muscle and on pork quality. *J. Sci. Food Agric.* 57:31–41. doi:10.1002/jsfa.2740570104
- Boler, D. D., S. R. Gabriel, H. Yang, R. Balsbaugh, D. C. Mahan, M. S. Brewer, F. K. McKeith, and J. Killefer. 2009. Effect of different dietary levels of natural-source vitamin E in grow-finish pigs on pork quality and shelf life. *Meat Sci.* 83:723–730. doi:10.1016/j.meatsci.2009.08.012
- Boler, D. D., C. L. Puls, D. L. Clark, M. Ellis, A. L. Schroeder, P. D. Matzat, J. Killefer, F. K. McKeith, and A. C. Dilger. 2014. Effects of immunological castration (Improvest) on changes in dressing percentage and carcass characteristics of finishing pigs. *J. Anim. Sci.* 92:359–368. doi:10.2527/jas.2013-6863
- Calder, P. C. 2018. Very long-chain n-3 fatty acids and human health: fact, fiction and the future. *Proc. Nutr. Soc.* 77:52–72. doi:10.1017/S0029665117003950
- Caspi, A., B. Williams, J. Kim-Cohen, I. W. Craig, B. J. Milne, R. Poulton, L. C. Schalkwyk, A. Taylor, H. Werts, and T. E. Moffitt. 2007. Moderation of breastfeeding effects on the IQ by genetic variation in fatty acid metabolism. *Proc. Natl. Acad. Sci. USA* 104:18860–18865. doi:10.1073/pnas.0704292104
- Cherian, G., and J. S. Sim. 1995. Dietary  $\alpha$ -linolenic acid alters the fatty acid composition of lipid classes in swine tissues. *J. Agric. Food Chem.* 43:2911–2916. doi:10.1021/jf00059a026Juarez
- Cromwell, G. L., M. J. Azain, O. Adeola, S. K. Baidoo, S. D. Carter, T. D. Crenshaw, S. W. Kim, D. C. Mahan, P. S. Miller, and M. C. Shannon; North Central Coordinating Committee on Swine Nutrition. 2011. Corn distillers dried grains with solubles in diets for growing-finishing pigs: a cooperative study. *J. Anim. Sci.* 89:2801–2811. doi:10.2527/jas.2010-3704
- D'Souza, D. N., and B. P. Mullan. 2002. The effect of genotype, sex and management strategy on the eating quality of pork. *Meat Sci.* 60:95–101. doi:10.1016/S0309-1740(01)00112-7
- Drey, L. N., L. L. Prill, B. A. Olson, E. A. Rice, J. M. Gonzalez, J. L. Vipham, T. A. Houser, E. A. E. Boyle, and T. G. O'Quinn. 2019. Evaluation of marbling and enhancement's abilities to compensate for reduced beef palatability at elevated degrees of doneness. *J. Anim. Sci.* 97:669–686. doi:10.1093/jas/sky435
- Elsbernd, A. J., J. F. Patience, and K. J. Prusa. 2016. A comparison of the quality of fresh and frozen pork from immunologically castrated males versus gilts, physical castrates, and entire males. *Meat Sci.* 111:110–115. doi:10.1016/j.meatsci.2015.07.003
- Gabler, N. K., J. D. Spencer, D. M. Webel, and M. E. Spurlock. 2007. In utero and postnatal exposure to long chain (n-3) PUFA enhances intestinal glucose absorption and energy stores in weanling pigs. *J. Nutr.* 137:2351–2358. doi:10.1093/jn/137.11.2351
- Guo, Q., B. T. Richert, J. R. Burgess, D. M. Webel, D. E. Orr, M. Blair, G. E. Fitzner, D. D. Hall, A. L. Grant, and D. E. Gerrard. 2006. Effects of dietary vitamin E and fat supplementation on pork quality. *J. Anim. Sci.* 84:3089–3099. doi:10.2527/jas.2005-456
- Haak, L., S. De Smet, D. Fremaut, K. Van Walleghem, and K. Raes. 2008. Fatty acid profile and oxidative stability of pork as influenced by duration and time of dietary linseed or fish oil supplementation. *J. Anim. Sci.* 86:1418–1425. doi:10.2527/jas.2007-0032
- Huff-Lonergan, E., T. J. Baas, M. Malek, J. C. Dekkers, K. Prusa, and M. F. Rothschild. 2002. Correlations among selected pork quality traits. *J. Anim. Sci.* 80:617–627. doi:10.2527/2002.803617x
- Jiang, J., X. Tang, Y. Xue, G. Lin, and Y. L. Xionga. 2017. Dietary linseed oil supplemented with organic selenium improved the fatty acid nutritional profile, muscular selenium deposition, water retention, and tenderness of fresh pork. *Meat Sci.* 131:99–106. doi:10.1016/j.meatsci.2017.03.014
- Juarez, M., M. E. R. Dugan, N. Aldai, J. L. Aalhus, J. F. Patience, R. T. Zijlstra, A. D. Beaulieu. 2010. Feeding

- co-extruded flaxseed to pigs: effects of duration and feeding level on growth performance and backfat fatty acid composition of grower-finisher pigs. *Meat Sci.* 84:578–584. doi:10.1016/j.meatsci.2009.10.015
- Juarez, M., M. E. R. Dugan, N. Aldai, J. L. Aalhus, J. F. Patience, R. T. Zijlstra, and A. D. Beaulieu. 2011. Increasing omega-3 levels through dietary co-extruded flaxseed supplementation negatively affects pork palatability. *Food Chem.* 126:1716–1723. doi:10.1016/j.foodchem.2010.12.065
- Kouba, M., M. Enser, F. M. Whittington, G. R. Nute, and J. D. Wood. 2003. Effect of a high-linolenic acid diet on lipogenic enzyme activities, fatty acid composition, and meat quality in the growing pig. *J. Anim. Sci.* 81:1967–1979. doi:10.2527/2003.8181967x
- Ma, X., Z. Jiang, and C. Lai. 2016. Significance of increasing n-3 PUFA content in pork on human health. *Crit. Rev. Food Sci. Nutr.* 56:858–870. doi:10.1080/10408398.2013.850059
- Miller, P. E., M. Van Elswyk, and D. D. Alexander. 2014. Long-chain omega-3 fatty acids eicosapentaenoic acid and docosahexaenoic acid and blood pressure: a meta-analysis of randomized controlled trials. *Am. J. Hypertens.* 27:885–896. doi:10.1093/ajh/hpu024
- Nakai, H., F. Saito, T. Ikeda, S. Ando, and A. Komatsu. 1975. Standard models of pork colour. *Bull. Natl. Inst. Anim. Ind. (Chiba)* 29:69–75.
- Nold, R. A., J. R. Romans, W. J. Costello, J. A. Henson, and G. W. Libal. 1997. Sensory characteristics and carcass traits of boars, barrows, and gilts fed high- or adequate-protein diets and slaughtered at 100 or 110 kilograms. *J. Anim. Sci.* 75:2641–2651. doi:10.2527/1997.75102641x
- Overholt, M. F., E. K. Arkfeld, D. A. Mohrhauser, D. A. King, T. L. Wheeler, A. C. Dilger, S. D. Shackelford, and D. D. Boler. 2016. Comparison of variability in pork carcass composition and quality between barrows and gilts. *J. Anim. Sci.* 94:4415–4426. doi:10.2527/jas.2016-0702
- NPPC. 1999. Official color and marbling standards. *Natl. Pork Prod. Council*, Des Moines, IA.
- Ntawubizi, M., K. Raes, N. Buys, and S. De Smet. 2009. Effect of sire and sex on the intramuscular fatty acid profile and indices for enzyme activities in pigs. *Livest. Sci.* 122:264–270. doi:10.1016/j.livsci.2008.09.008
- Otten, W., C. Wirth, P. A. Laizzo, and H. M. Eichinger. 1993. A high omega-3 fatty acid diet alters fatty acid composition of heart, liver, kidney, adipose tissue and skeletal muscle in swine. *Annu. Nutr. Metab.* 137:134–141. doi:10.1159/000177761
- Overholt, M. F., E. K. Arkfeld, D. A. Mohrhauser, D. A. King, T. L. Wheeler, A. C. Dilger, S. D. Shackelford and D. D. Boler. 2016. Comparison of variability in pork carcass composition and quality between barrows and gilts. *J. Anim. Sci.* 94:4415–4426. doi:10.2527/jas.2016-0702
- Park, P., and R. E. Goins. 1994. In situ preparation of flume for analysis of fatty acid composition in food. *J. Food Sci.* 59:1262–1266. doi:10.1111/j.1365-2621.1994.tb14691.x
- Phelps, K. J., J. S. Drouillard, T. G. O'Quinn, D. D. Burnett, T. L. Blackmon, J. Axtman, C. L. Van Bibber-Krueger, and J. M. Gonzalez. 2016. Feeding microalgae meal (All-G Rich™, *Schizochytrium limacinum* CCAP 4087/2) to beef heifers I: effects on fresh meat quality. *J. Anim. Sci.* 94:4016–4029. doi:10.2527/jas2016-0487
- Phillips, A. L., C. Faustman, M. P. Lynch, K. E. Govoni, T. A. Hoagland, and S. A. Zinn. 2001. Effect of dietary  $\alpha$ -tocopherol supplementation on color and lipid stability in pork. *Meat Sci.* 58:389–393. doi:10.1016/S0309-1740(01)00039-0
- Phillips, C. M., L. Goumidi, S. Bertrais, M. R. Field, J. M. Ordovas, L. A. Cupples, C. Defoort, J. A. Lovegrove, C. A. Drevon, E. E. Blaak, et al. 2010. Leptin receptor polymorphisms interact with polyunsaturated fatty acids to augment risk of insulin resistance and metabolic syndrome in adults. *J. Nutr.* 140:238–244. doi:10.3945/jn.109.115329
- Ramirez, R., and R. Cava. 2007. Carcass composition and meat quality of three different Iberian X Duroc genotype pigs. *Meat Sci.* 75:388–396. doi:10.1016/j.meatsci.2006.08.003
- Rice, E. A. 2019. The effect of increased pork hot carcass weights on loin quality, consumer appearance and purchase intent ratings, and palatability ratings of top loin chops. Master's Thesis, Kansas State University, Manhattan, KS.
- Romans, J. R., R. C. Johnson, D. M. Wulf, G. W. Libal, and W. J. Costello. 1995a. Effects of ground flaxseed in swine diets on pig performance and on physical and sensory characteristics and omega-3 fatty acid content of pork: I. dietary level of flaxseed. *J. Anim. Sci.* 73:1982–1986. doi:10.2527/1995.7371982x
- Romans, J. R., D. M. Wulf, R. C. Johnson, G. W. Libal, and W. J. Costello. 1995b. Effects of ground flaxseed in swine diets on pig performance and on physical and sensory characteristics and omega-3 fatty acid content of pork: II. duration of 15% dietary flaxseed. *J. Anim. Sci.* 73:1987–1999. doi:10.2527/1995.7371987x
- Salem, N., and M. Eggersdorfer. 2015. Is the world supply of omega-3 fatty acids adequate for optimal human nutrition? *Curr. Opin. Clin. Nutr. Meta. Care* 18:147–154. doi:10.1097/MCO.0000000000000145
- Sales, J., and V. Koukolová. 2011. Dietary vitamin E and lipid and color stability of beef and pork: modeling of relationships. *J. Anim. Sci.* 89:2836–2848. doi:10.2527/jas.2010-3335
- Simopoulos, A. P. 2000. Human requirement of N-3 polyunsaturated fatty acids. *Poult. Sci.* 79:961–970. doi:10.1093/ps/79.7.961
- Simopoulos, A. P. 2016. An increase in the omega6/omega-3 fatty acid ratio increases the risk of obesity. *Nutri.* 8:1–17. doi:10.3390/nu8030128
- Stephenson, E. W., M. A. Vaughn, D. D. Burnett, C. B. Paulk, M. D. Tokach, S. S. Dritz, J. M. DeRouchey, R. D. Goodband, J. C. Woodworth and J. M. Gonzalez. 2016. Influence of dietary fat source and feeding duration on finishing pig growth performance, carcass composition, and fat quality. *J. Anim. Sci.* 94:2851–2866. doi:10.2527/jas2015-9521
- Van Oeckel, M. J., M. Casteels, N. Warnants, L. Van Damme, and C. V. Boucqu ea. 1996. Omega-3 fatty acids in pig nutrition: implications for the intrinsic and sensory quality of the meat. *Meat Sci.* 44:55–63. doi:10.1016/S0309-1740(96)00077-0
- Vatansever, L., E. Kurt, M. Enser, G. R. Nute, N. D. Scollan, J. D. Wood, and R. I. Richardson. 2000. Shelf life and eating quality of beef from cattle of different breeds given diets differing in n-3 polyunsaturated fatty acid composition. *Anim. Sci.* 71:471–482. doi:10.1017/S135772980005548X



- Wang, H., L. S. Wang, B. M. Shi, and A. S. Shan. 2012. Effects of dietary corn dried distillers grains with solubles and vitamin E on growth performance, meat quality, fatty acid profiles, and pork shelf life of finishing pigs. *Live. Sci.* 149:155–166. doi:10.1016/j.livsci.2012.07.009
- Warnants, N., M. J. Van Oeckel, and C. V. Boucque. 1999. Incorporation of dietary polyunsaturated fatty acids into pork fatty tissues. *J. Anim. Sci.* 77:2478–2490. doi:10.2527/1999.7792478x
- Waylan, A. T., P. R. O'Quinn, J. A. Unruh, J. L. Nelssen, R. D. Goodband, J. C. Woodworth, M. D. Tokach, and S. I. Koo. 2002. Effects of modified tall oil and vitamin E on growth performance, carcass characteristics, and meat quality of growing-finishing pigs. *J. Anim. Sci.* 80:1575–1585. doi:10.2527/2002.8061575x
- Zhang, S., T. J. Knight, K. J. Stalder, R. N. Goodwin, S. M. Lonergan, and D. C. Beitz. 2007. Effects of breed, sex and halothane genotype on fatty acid composition of pork longissimus muscle. *J. Anim. Sci.* 85:583–591. doi:10.2527/jas.2006-239
- Zhang, S., T. J. Knight, K. J. Stalder, R. N. Goodwin, S. M. Lonergan, and D. C. Beitz. 2008. Effects of breed, sex and halothane genotype on fatty acid composition of triacylglycerols and phospholipids in pork longissimus muscle. *J. Anim. Breed. Genet.* 126:259–268. doi:10.1111/j.1439-0388.2008.00782.x