Title: Improving the economic efficiency of fat utilization in pig diets by better quantifying the energy value of fat sources based on their chemical composition, **NPB #16-010**

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Industry summary

The overall objective of this project was to provide pork producers with accurate energy values for various dietary fat sources based on their chemical composition (free fatty acid levels, MIU content, and degree of unsaturation). Our hypothesis was dietary fat sources that had low free fatty acid levels and were highly unsaturated would have the greatest energy value compared to the other dietary fat sources. To test our hypothesis and accomplish the project objective we selected 14 dietary fat sources that were diverse in their chemical composition. A total of 120 Genetiporc 6.0 × Genetiporc F25 (PIC, Inc., Hendersonville, TN) individually housed barrows were studied for 56 d. These barrows (initial BW of 9.9 ± 0.6 kg) were randomly allotted to 1 of 15 dietary treatments. Each experimental diet included 95% of a corn-soybean meal basal diet plus 5% either: corn starch or 1 of 14 dietary fat sources. The 14 dietary fat sources were: animal-vegetable blend, canola oil, 2 sources of choice white grease, coconut oil, 2 sources of corn oil, fish oil, flaxseed oil, palm oil, poultry fat, 2 sources of soybean oil, and tallow. Pigs were limit-fed experimental diets from d 0 to 10 and d 46 to 56 providing a 7 d adaption for fecal collection on d 7 to 10 (13 kg BW) and d 53 to 56 (50 kg BW). At 13 kg BW, the average energy content of the 14 sources was 8.42 Mcal of DE/kg, 8.26 Mcal of ME/kg, and 7.27 Mcal of NE/kg, respectively. At 50 kg BW, the average energy content was 8.45 Mcal of DE/kg, 8.28 Mcal of ME/kg, and 7.29 Mcal of NE/kg, respectively. At 13 kg BW, variation of dietary fat DE content was explained by: DE (Mcal/kg) = 9.363 + [0.097 × (FFA, %)] – [0.016 × Omega-6:Omega-3] – [1.240 × (arachidic acid, %)] – [5.054 × (insoluble impurities, %)] + [0.014 × (palmitic acid, %)] ($P = 0.008$; $R^2 = 0.82$). At 50 kg BW, variation of dietary fat DE content was explained by: DE (Mcal/kg) = 8.357 + [0.189 × U:S] – [0.195 × (FFA, %)] – [6.768 × (behenic acid, %)] + [0.024 × (PUFA, %)] ($P = 0.002$; $R^2 = 0.81$). In summary, the chemical composition of dietary fat explained a large degree of the variation observed in the energy content of dietary fat sources. The Powles et al. (1995) equation accurately predicted the average DE content from the 14 sources (8.43 Mcal/kg), but underestimated the DE content of medium chain SFA sources and the negative impact of increased FFA level to a large degree. Further research is needed to validate if the equations generated herein are more precise in predicting dietary fat DE variation among sources. This validation was done in a commercial scale research facility in collaboration with Hanor Co. Using choice white grease and corn oil it was found in Experiment 2 that the equation generated in Experiment 1 in 50 kg pigs had less prediction error (0.11) and bias (0.33) than the equation reported by Powles et al. (1995). These regression equations were generated using apparent total tract digestibility of fat, but the novelty of this experiment was to investigate the impact endogenous losses of fat (ELF) had on the energy value of dietary fat sources. Endogenous losses of fat, is the amount of fat that is present in the feces of non-dietary origin. An additional 8 barrows (average initial BW of 9.9 ± 0.6 kg) were utilized to determine ELF. Estimated ELF at 9 kg BW was 4.17 g/kg of DM intake ($P < 0.001$). Estimated ELF at 38 kg BW was 6.67 g/kg of DM intake ($P = 0.002$). Adding 5% dietary fat regardless of source compared to pigs fed 5% corn starch increased the ATTD and STTD of AEE at both fecal collection time points ($P < 0.001$). At 13 kg BW, the STTD of AEE was the greatest in barrows fed CANO-, CWGA-, and FISH-based diets and was the least in pigs fed PALM- and TAL-based diets ($P < 0.001$). The average STTD of AEE among the 14 dietary fat sources at 13 kg BW was 93.7% and the range was 3.20%. At 50 kg BW, ATTD and STTD of AEE was the greatest in pigs fed a CANO-based diet and the least in pigs fed a CORA-based diet ($P < 0.001$). The average of STTD of AEE among the 14 dietary fat sources at 50 kg BW was 96.8% and the range was 4.22%. On average ELF accounted for 43.1% and 68.0% of the fecal AEE both fecal collection points, respectively. The substantial proportion of AEE contained in feces that is of ELF origin and not of dietary origin implies that the current estimates of the DE content of dietary fat are underestimated. Not correcting for ELF, resulted in underestimating dietary fat DE content by 0.42 and 0.60 Mcal/kg at 13 and 50 kg of BW, respectively. In conclusion, the DE content of dietary fat can be predicted by the dietary fat source's chemical composition. However, further work is needed on determining the NE content of dietary fat sources.

Keywords

Dietary fat, energy, lipid metabolism, endogenous losses of fat, pigs, swine

Scientific abstract

The objective was to determine the energy concentration for a diverse array of dietary fat sources and from these data, develop regression equations that explain differences based on chemical composition. A total of 120 Genetiporc 6.0 × Genetiporc F25 (PIC, Inc., Hendersonville, TN) individually housed barrows were studied for 56 d. These barrows (initial BW of 9.9 ± 0.6 kg) were randomly allotted to 1 of 15 dietary treatments. Each experimental diet included 95% of a corn-soybean meal basal diet plus 5% either: corn starch or 1 of 14 dietary fat sources. The 14 dietary fat sources (animal-vegetable blend, canola oil, choice white grease source A, choice white grease source B, coconut oil, corn oil source A, corn oil source B, fish oil, flaxseed oil, palm oil, poultry fat, soybean oil source A, soybean oil source B, and tallow) were selected to provide a diverse and robust range of U:S (unsaturated fatty acid:SFA). Pigs were limit-fed experimental diets from d 0 to 10 and d 46 to 56 providing a 7 d adaption for fecal collection on d 7 to 10 (13 kg BW) and d 53 to 56 (50 kg BW). At 13 kg BW, the average energy content of the 14 sources was 8.42 Mcal of DE/kg, 8.26 Mcal of ME/kg, and 7.27 Mcal of NE/kg, respectively. At 50 kg BW, the average energy content was 8.45 Mcal of DE/kg, 8.28 Mcal of ME/kg, and 7.29 Mcal of NE/kg, respectively. At 13 kg BW, variation of dietary fat DE content was

explained by: DE (Mcal/kg) = 9.363 + [0.097 × (FFA, %)] – [0.016 × Omega-6:Omega-3] – [1.240 × (arachidic acid, %)] – [5.054 × (insoluble impurities, %)] + [0.014 × (palmitic acid, %)] (P = 0.008; R^2 = 0.82). At 50 kg BW, variation of dietary fat DE content was explained by: DE (Mcal/kg) = 8.357 + [0.189 × U:S] – [0.195 × (FFA, %)] – [6.768 × (behenic acid, %)] + [0.024 × (PUFA, %)] (P = 0.002; R^2 = 0.81). In summary, the chemical composition of dietary fat explained a large degree of the variation observed in the energy content of dietary fat sources. The Powles et al. (1995) equation accurately predicted the average DE content from the 14 sources (8.43 Mcal/kg), but underestimated the DE content of medium chain SFA sources and the negative impact of increased FFA level to a large degree. A further validation of this equation was conducted in a commercial scale research facility (Hanor Co.). Using choice white grease and corn oil it was found in Experiment 2 that the equation generated in Experiment 1 in 50 kg pigs had less prediction error (0.11) and bias (0.33) than the equation reported by Powles et al. (1995).These regression equations were generated using apparent total tract digestibility of fat, but the novelty of this experiment was to investigate the impact endogenous losses of fat (ELF) had on the energy value of dietary fat sources. An additional 8 barrows (average initial BW of 9.9 ± 0.6 kg) were utilized to determine ELF. Pigs were housed individually throughout the 56 d experiment. Estimated ELF at 9 kg BW was 4.17 g/kg of DM intake (P < 0.001). Estimated ELF at 38 kg BW was 6.67 g/kg of DM intake (P = 0.002). Adding 5% dietary fat regardless of source compared to pigs fed 5% corn starch increased the ATTD and STTD of AEE at both fecal collection time points (P < 0.001). At 13 kg BW, the STTD of AEE was the greatest in barrows fed CANO-, CWGA-, and FISH-based diets and was the least in pigs fed PALM- and TAL-based diets (P < 0.001). The average STTD of AEE among the 14 dietary fat sources at 13 kg BW was 93.7% and the range was 3.20%. At 50 kg BW, ATTD and STTD of AEE was the greatest in pigs fed a CANO-based diet and the least in pigs fed a CORA-based diet (P < 0.001). The average of STTD of AEE among the 14 dietary fat sources at 50 kg BW was 96.8% and the range was 4.22%. On average ELF accounted for 43.1% and 68.0% of the fecal AEE both fecal collection points, respectively. The substantial proportion of AEE contained in feces that is of ELF origin and not of dietary origin implies that the current estimates of the DE content of dietary fat are underestimated. Not correcting for ELF, resulted in underestimating dietary fat DE content by 0.42 and 0.60 Mcal/kg at 13 and 50 kg of BW, respectively.

Introduction

Fat is included in swine diets as a source of energy when the cost is economically advantageous. However, DE, ME and NE content estimates of dietary fat have been variable and have not been fully validated in commercial conditions (Kil et al., 2011; Boyd et al., 2015). A lack of precision in defining the energy value of dietary fat could lead to losses for pork producers due to incorrect costing in diet formulations and disappointing performance outcomes.

Prediction equations compiled by Powles et al. (1995) using data from Wiseman et al. (1990) and Powles et al. (1993, 1994) have been commonly used to estimate the energy content of fat sources by using the unsaturated fatty acid to SFA ratio (U:S) and FFA level. The ME and NE content is then often estimated from DE according to van Milgen et al. (2001) who suggested that ME is 98% of DE and NE is 88% of ME. The NRC (2012) points out that the equation accuracy across all compositions and characteristics of dietary fat sources is unknown. Boyd et al. (2015) recently utilized a growth assay to determine the NE content of choice white grease and reported a 14% difference compared to the NRC (2012) estimate. Clearly, validation and refinement of the energy values assigned to dietary fat sources in swine is needed. Including dietary fatty acid concentration and more detailed chemical composition along with FFA and U:S content across a diverse and robust range of dietary fat sources may generate a more accurate estimate of the DE, ME and NE of dietary fat.

Objectives

Our overall objective was **to provide pork producers with accurate energy values for various dietary fat sources based on their chemical composition.** The central hypotheses of this study were 1) that the equations currently used by the American industry were developed 25 years ago in Britain and have never been validated. and 2) that evaluating these equations, and modifying them if necessary, based on the results of intensive digestion studies and commercial-scale growth studies, will provide our industry with the best possible ME and NE values of fat sources

Specific objectives:

1. To generate a predictive regression equation to determine the ME and NE values of dietary fat sources based on chemical structure
2. To test the generated energy values of dietary fat source in comparison to the current NRC, 2012 values in a commercial situation
3. To undertake these evaluations at 2 different body weights

Materials and methods

Experiment 1: generation of prediction equation

All experimental procedures adhered to guidelines for the ethical and humane use of animals for research, and were approved by the Iowa State University Institutional Animal Care and Use Committee (#2-16-8201-S).

Animals, Housing, and Experimental Design

A total of 120 Genetiporc 6.0 × Genetiporc F25 (PIC, Inc., Hendersonville, TN) barrows in 2 sequential replicate groups of 60 barrows each were studied. These barrows (initial BW of 9.9 ± 0.6 kg) were allotted at random to 1 of 15 dietary treatments: (control [CNTR], animal-vegetable blend [AV], canola oil [CANO], choice white grease source A [CWGA], choice white grease source B [CWGB], coconut oil [COCO], corn oil source A [CORA], corn oil source B [CORB], fish oil [FISH], flaxseed oil [FLAX], palm oil [PALM], poultry fat [POUF], soybean oil source A [SOYA], soybean oil source B [SOYB], and tallow [TAL]). An additional 8 barrows (average initial BW of 9.9 ± 0.6 kg) were utilized to determine ELF. Pigs were housed individually throughout the 56 d experiment.

Pigs were housed individually throughout the 56 d experiment. From d 0 to 28 pigs were housed in a room in which each pen provided 0.50 m^2 of floor space per pig, a nipple drinker, and a stainless steel feeder and had mesh metal flooring. From d 28 to 56 pigs were housed in a room in which each pen provided 1.83 m^2 of floor space per pig, a nipple drinker, and a composite feeder and had slatted concrete flooring.

Diets and Feeding

Each experimental diet (Table 1 and 2) included 95% of a corn-soybean meal basal diet plus 5% of either: corn starch (CNTR) or 1 of the previously listed 14 dietary fat sources. Pigs were fed their assigned diets from d 0 to

10 (Table 1) and d 46 to 56 (Table 2). These experimental periods provided a 7 d acclimation to the diet prior to fecal collection. Pigs were fed the same fat source in both experimental periods and fed a common diet between experimental periods (d 10 to 46; Table 3). Feed allowance was limited from d 0 to 10 to provide a daily energy intake of 2.8 times maintenance (NRC, 2012). From d 10 to 46 feed was provided ad libitum. Feed allowance was limited from d 46 to 56 to provide a daily energy intake of 3.2 times maintenance (NRC, 2012). Feed allowances were selected for each phase to maximize intake without having variation of feed intake among pigs. Water was provided ad libitum at all times from d 0 to 56. Dietary fat sources were selected to provide a diverse range of degree of unsaturation. The chemical composition and the fatty acid profile of the sources of dietary fat are presented in Tables 4, 5 and 6, respectively.

Representative feed samples were collected at the time of mixing and stored at -20°C for later analysis. Representative dietary fat samples were collected by subsampling from a minimum of 5 different locations. The subsamples of dietary fat were taken from the top, middle, and bottom, as well as, the center and peripheral of the container of fat. These samples were then homogenized and stored at -20°C to provide a representative sample for later analysis. Prior to the initiation of the experiment, pigs were fed a common post-weaning nursery diet.

Data and Sample Collection

Pigs were individually weighed on d 0, 7, 10, 22, 46, 53, and 56. Fecal grab samples were collected fresh from 0800 to 1000 h and 1600 to 1800 h on d 7 to 10 and d 53 to 56. Fecal samples were immediately stored at -20°C for later analysis.

Analytical Methods

Feed and fecal samples were homogenized, dried, and then finely ground through a 1 mm screen in a Retsch grinder (model ZMI; Retsch Inc., Newtown, PA). All feed analyses were performed in duplicate unless otherwise noted and repeated when the intraduplicate CV was greater than 1%. Acid hydrolyzed ether extract (method 2003.06; AOAC, 2007) was analyzed using a SoxCap SC 247 hydrolyzer and a Soxtec 255 semiautomatic extractor (FOSS North America, Eden Prairie, MN). Dry matter was determined by drying samples in an oven at 105°C to a constant weight. Gross energy was determined using an isoperibolic bomb calorimeter (model 6200; Parr Instrument Co., Moline, IL). Benzoic acid (6.318 Mcal/kg; Parr Instrument Co.) was used as the standard for calibration and determined to contain 6.319 ± 0.005 Mcal of GE/kg. Titanium dioxide was determined by spectrophotometer (synergy 4; BioTek Instruments Inc., Winooski, VT) according to the method of Leone (1973). Dietary fat sources were analyzed in duplicate by a commercial laboratory (Barrow-Agee Laboratories, Memphis, TN) to determine fatty acid content (method Ce 1-62; AOCS, 2009), FFA (Ca 5a-40; AOCS, 2009), moisture and volatile matter (MOVM; Ca 2c-25; AOCS, 2009), insoluble impurities (INIM; Ca 3a-46, AOCS, 2009), unsaponifiable matter (UNS; Cb-53, AOCS, 2009), and initial peroxide value (PV; Cd 8b-90; AOCS, 2009).

Calculations

Basal diet DE was determined using the following equation: $DE_{basal\ diet} = \{DE_{CNTR\ diet} - [DE_{corn\ starch}$ (4.000 Mcal/kg; NRC, 1998) × proportion of corn starch added to the basal diet (5%)]} × 1.05. Energy value for each dietary fat source was determined according to the following equations: $DE_{dietary\ fat}$ (Mcal/kg) = $\{DE_{test\ diet} - [DE_{basal\ diet} \times (1 -$ proportion of dietary fat in the diet; 5%)]}/proportion of dietary fat in the diet; 5% (Villamide, 1996); $ME_{dietary\ fat}$ (Mcal/kg) = $DE_{dietary\ fat}$ × 98% (van Milgen et al., 2001); $NE_{dietary\ fat}$ (Mcal/kg) = $ME_{dietary\ fat}$ × 88% (van Milgen et al., 2001). All energy content values are reported on an as-fed basis. Iodine value was calculated from the fatty acid profile using the following equation: IV = [C16:1] × (0.95) + [C18:1] × (0.86) + [C18:2] × (1.732) + [C18:3] × (2.616) + [C20:1] × (0.795) + [C20:2] × (1.57) + [C20:3] × (2.38) + [C20:4] × (3.19) + [C20:5] × (4.01) + [C22:4] × (2.93) + [C22:5] × (3.68) + [C22:6] × (4.64); brackets indicate percentage concentration (Meadus et al., 2010).

The apparent total tract digestibility (ATTD; %) of AEE was calculated as 100 – {100 × [concentration (g) of TiO2 in diet × concentration of (g) of AEE in feces]/[concentration (g) of TiO2 in feces × concentration of (g) AEE in diet]} (Oresanya et al. 2007). The ELF was determined in pigs fed fat-free diets by the following equation: ELF (g/kg of DM intake) = [g of AEE/kg of feces] - [g of AEE/kg of feed]. The standardized total tract digestibility (STTD; %) of AEE was calculated as ATTD of AEE, % + {[ELF (g/kg of DM intake)/concentration (g) of AEE in diet] × 100} (Stein et al., 2007).
Determination of the energy content of dietary fat sources was based on the ATTD or STTD of AEE. The DE content of dietary fat not corrected for ELF was calculated by the following equation: apparent $DE_{dietary\ fat}$ (Mcal/kg) = $GE_{dietary\ fat}$ (9.4 Mcal/kg; Atwater and Bryant, 1900; NRC, 2012) × ATTD of AEE. The DE content of dietary fat corrected for ELF was calculated by the following equation: corrected $DE_{dietary\ fat}$ (Mcal/kg) = $GE_{dietary\ fat}$ (9.4 Mcal/kg; Atwater and Bryant, 1900; NRC, 2012) × STTD of AEE. Further determination of ME and NE content of dietary fat was calculated by MEdietary fat (Mcal/kg) = DE × 98% and $NE_{dietary\ fat}$ (Mcal/kg) = ME × 88% (van Milgen et al., 2001; NRC, 2012).

Statistical Analysis
These data were analyzed using PROC MIXED (SAS 9.4; SAS Inst. Inc., Cary, NC) with dietary treatment (n = 15) as a fixed effect, replicate (n = 2; 60 barrows each) as a random effect, and pig (n = 120) as the experimental unit. The comparison of the relationship between DE, ME, or NE content and the chemical composition of the 14 dietary fat sources were analyzed using PROC CORR and PROC REG. Correlation coefficients are reported as Pearson coefficients. Multivariate regression models were determined via stepwise selection with a significance stay level of 0.15. The dietary fat source multivariate factors included: fatty acid concentrations, SFA, MUFA, PUFA, Omega-3, Omega-6, IV, U:S, FFA, MOVA, INIM, UNS, MIU, and PV. The equation generated from each step of the regression analysis was reported sequentially. For each variable, normal distribution of residuals was tested using PROC UNIVARIATE.

To compare the observed dietary fat energy values herein to the previous equation reported by Powles et al. (1995), the standard error of prediction (prediction error [PE]) and prediction bias (PBias) were calculated using the following equations: PE = $\sqrt{}$ [(1/number of dietary fat treatments) × Σ (absolute differences between predicted and observed energy values)^2] and PBias = [(1/number of dietary fat treatments) × Σ (difference between predicted and observed energy values)] (smaller absolute value indicates greater accuracy of the equation; negative value indicates underestimation and positive value indicates overestimation; Lane et al., 2014).

Non-detectable fatty acid concentrations were treated in all statistical analyses as 0. All *P*-values < 0.050 were considered significant and *P*-values between 0.050 and 0.100 were considered trends.

Experiment 2: validation of prediction equation

All experimental procedures adhered to guidelines for the ethical and humane use of animals for research, and were approved by the Iowa State University Institutional Animal Care and Use Committee (#2-17-8443-S).

Animal, Housing, and Experimental Design

A total of 947 barrows in 50 pens and 959 gilts in another 51 pens were studied from ~ 31 kg to 68 kg over a 35 day period in a commercial research facility (Hanor Co.). These 101 pens (19 pigs per pen) were allotted at random to 1 of 7 dietary treatments; a control and 6 dietary fat treatments. A corn-soybean meal based diet with no added dietary fat was the control and energy reference. The 6 dietary fat treatments were 2 dietary fat sources (choice white grease and corn oil) included at 3 different levels (2, 4, and 6%, respectively).

Diets and Feeding

Three diets were manufactured for this experiment (Table 18). These diets were then blended together, to create the remaining 4 dietary treatments (Table 19). This resulted in the 7 dietary treatments as outlined above. The analyzed compositions of these 7 treatment diets are located in Table 20. Representative feed samples were collected at the time of mixing and stored at -20°C for later analysis. Representative dietary fat samples were collected. These samples were then homogenized and stored at -20°C to provide a representative sample for later analysis. Prior to the initiation of the experiment, pigs were fed a common post-weaning nursery diet. Water was provided ad libitum at all times from d 0 to 35. The 2 dietary fat sources (choice white grease and corn oil) were selected to provide differences in degree of unsaturation and free fatty acid concentration level. The chemical composition and the fatty acid profile of the 2 dietary fat sources used are presented in Table 21. Titanium Dioxide was added as an indigestible marker to all experimental diets at 0.40% in replacement of corn from d 14 to 21.

Data and Sample Collection

Pigs were weighed as a pen on d 0 and 35. Fecal grab samples were collected fresh on d 19 from a minimum of 3 pigs per pen. Fecal samples were immediately stored at -20°C for later analysis.

Analytical Methods

Feed and fecal samples were homogenized, dried, and then finely ground through a 1 mm screen in a Retsch grinder (model ZMI; Retsch Inc., Newtown, PA). All feed analyses were performed in duplicate unless otherwise noted and repeated when the intraduplicate CV was greater than 1%. Acid hydrolyzed ether extract (method 2003.06; AOAC, 2007) was analyzed using a SoxCap SC 247 hydrolyzer and a Soxtec 255 semiautomatic extractor (FOSS North America, Eden Prairie, MN). Dry matter was determined by drying samples in an oven at 105°C to a constant weight. Gross energy was determined using an isoperibolic bomb calorimeter (model 6200; Parr Instrument Co., Moline, IL). Benzoic acid (6.318 Mcal/kg; Parr Instrument Co.) was used as the standard for calibration and determined to contain 6.316 ± 0.003 Mcal of GE/kg. Titanium dioxide was determined by spectrophotometer (synergy 4; BioTek Instruments Inc., Winooski, VT) according to the method of Leone (1973). Dietary fat sources were analyzed in duplicate by a commercial laboratory (Barrow-Agee Laboratories, Memphis, TN) to determine fatty acid content (method Ce 1-62; AOCS, 2009), FFA (Ca 5a-40; AOCS, 2009), moisture and volatile matter (MOVM; Ca 2c-25; AOCS, 2009), insoluble impurities (INIM; Ca 3a-46, AOCS, 2009), unsaponifiable matter (UNS; Cb-53, AOCS, 2009), and initial peroxide value (PV; Cd 8b-90; AOCS, 2009).

Calculations

The apparent total tract digestibility (ATTD; %) of AEE was calculated as 100 – {100 × [concentration (g) of TiO_2 in diet × concentration of (g) of AEE in feces]/[concentration (g) of TiO_2 in feces × concentration of (g) AEE in diet]} (Oresanya et al. 2007). DE of dietary fat was determined as the slope + the y-intercept of the respective regression equation.

Statistical Analysis

These data were analyzed using PROC MIXED (SAS 9.4; SAS Inst. Inc., Cary, NC) with dietary treatment (n = 7) as a fixed effect and pig (n = 120) as the experimental unit. The determination of the DE of the 2 respective dietary fat sources based on the ATTD of dietary GE was determined using PROC REG. For each variable, normal distribution of residuals was tested using PROC UNIVARIATE.

To compare the observed dietary fat energy values herein to the equation generated in Experiment 1 (Kellner et al., 2017) and the equation reported by Powles et al. (1995), the standard error of prediction (prediction error [PE]) and prediction bias (PBias) were calculated using the following equations: PE = $\sqrt{}$ [(1/number of dietary fat treatments) × Σ (absolute differences between predicted and observed energy values)^2] and PBias = [(1/number of dietary fat treatments) × Σ (difference between predicted and observed energy values)] (smaller absolute value indicates greater accuracy of the equation; negative value indicates underestimation and positive value indicates overestimation; Lane et al., 2014).

Non-detectable fatty acid concentrations were treated in all statistical analyses as 0. All *P*-values < 0.050 were considered significant and *P*-values between 0.050 and 0.100 were considered trends.

Results

<u>Experiment 1: generation of prediction equation</u>

Determination of DE, ME and NE content of dietary fat sources

Dietary DE (Table 7) at 13 kg BW (d 7 to 10) was greater when dietary fat was added regardless of source in comparison to barrows fed CNTR (*P* < 0.001). The least dietary DE and estimated dietary fat DE, ME and NE were observed in pigs fed CORA-based diet (a moderately unsaturated but high FFA source) and the second least dietary DE and estimated dietary fat DE, ME and NE content were observed in pigs fed the COCO-based diet (the most saturated dietary fat source; *P* < 0.001). Across all the dietary fat sources tested at 13 kg BW, the average determined dietary fat DE was 8.42 Mcal/kg, ME was 8.26 Mcal/kg, and NE was 7.27 Mcal/kg; range in DE among the 14 dietary fat sources was 2.14 Mcal/kg (as-fed basis).

Adding dietary fat regardless of source increased the dietary DE (Table 8) at 50 kg BW (d 53 to 56) in comparison to pigs fed CNTR (*P* < 0.001). Dietary DE and estimated dietary fat DE, ME and NE were the greatest in the highly unsaturated dietary fat sources CANO and FLAX and the lowest DE, ME and NE were observed in AV- and CORA- (two sources with ≥ 7% FFA) based diets ($P < 0.001$). Across the 14 dietary fat sources tested at 50 kg BW, the average determined DE was 8.45 Mcal/kg, ME was 8.28, and NE was 7.29 Mcal/kg; the range in DE among the 14 dietary fat sources was 2.09 Mcal/kg (as-fed basis).

Relationship between dietary fat DE and chemical composition of dietary fat sources

At 13 kg BW, the dietary fat source DE content tended to be negatively correlated with Omega-6:Omega-3, FFA, and MOVM content ($P \leq 0.090$; Table 9). At 50 kg BW, the dietary fat source DE content was positively correlated with U:S ($P = 0.042$; Table 9). In addition, dietary fat DE tended to be positively correlated with linolenic acid and MUFA:SFA (C18:3; $P \leq 0.080$; Table 9).

The DE, ME and NE variation among dietary fat sources at 13 kg BW was largely explained ($R^2 = 0.82$) by a stepwise regression model with intercepts of 9.36, 9.18, and 8.08 Mcal/kg for DE, ME and NE respectively (Table 10). The model suggest that the energy value of dietary fat declines with increased FFA, Omega-6:Omega-3, INIM, and C20:0 content and increases with increasing C16:0 concentration ($P = 0.008$).

The variation in DE, ME and NE in 50 kg pigs was largely explained ($R^2 = 0.81$) by a stepwise regression model with intercepts of 8.35, 8.19, and 7.21 Mcal/kg for DE, ME and NE, respectively; Table 10). The model further suggested that the energy value of dietary fat was increased by increased dietary fat U:S and PUFA content and declined with increased FFA level and behenic acid (C22:0) concentration ($P = 0.002$).

Estimation of total tract ELF

Estimated ELF at 9 kg BW (d 7 to 10) was 4.17 g/kg of DM intake ($P < 0.001$; Table 14). Estimated ELF at 38 kg BW (d 53 to 56) was 6.67 g/kg of DM intake ($P = 0.002$). This represented a 46% increase in ELF from the lighter BW.

Effects of dietary fat source on ATTD and STTD of AEE

Adding 5% dietary fat regardless of source compared to pigs fed CNTR (5% corn starch) increased the ATTD of AEE and the STTD of AEE at both fecal collection time points ($P < 0.001$; Table 15). Among diets with fat added, the ATTD of AEE at 13 kg BW was the greatest in pigs fed CANO- and FISH-based diets and was the least in pigs fed PALM- and TAL-based diets ($P < 0.001$). The STTD of AEE was the greatest in barrows fed CANO-, CWGA-, and FISH-based diets and was the least in pigs fed PALM- and TAL-based diets ($P < 0.001$). The range of STTD of AEE among dietary fat sources analyzed at 13 kg BW was 3.20%. At 50 kg BW, ATTD and STTD of AEE was the greatest in pigs fed a CANO-based diet and the least in pigs fed a CORA-based diet ($P < 0.001$; Table 15). The range of STTD of AEE among dietary fat sources analyzed at 50 kg BW was 4.22%.

Table 16 provides the g/kg of DM intake of AEE intake, disappearance, and fecal excretion used to determine the ATTD and STTD of AEE of the 15 dietary treatments. Furthermore, it shows ELF on average accounted for 43.1% and 68.0% of the fecal AEE at both collection time points, respectively.

Apparent and corrected energy content of dietary fat

Due to the method of calculation, dietary fat source had the same impact on the dietary fat energy content as it had on ATTD and STTD of AEE (Table 17). At 13 kg BW, the average apparent energy content of the 14 dietary fat sources was 8.39, 8.28, and 7.23 of DE, ME and NE of Mcal/kg, respectively. After the correction for ELF contained in fecal matter, the corrected energy content of the 14 dietary fat sources was 8.81, 8.63, and 7.60 of DE, ME and NE of Mcal/kg, respectively.

At 50 kg BW, the average apparent energy content of the 14 dietary fat sources was 8.50, 8.33, and 7.33 of DE, ME and NE of Mcal/kg, respectively (Table 17). After the correction for ELF, the corrected energy content of the 14 dietary fat sources was 9.10, 8.92, and 7.85 of DE, ME and NE of Mcal/kg, respectively. The difference between the apparent and corrected DE content of dietary fat was 0.42 and 0.60 Mcal/kg at 13 and 50 kg BW, respectively.

Experiment 2: validation of prediction equation

Impact of dietary fat source and inclusion level on growth performance and feed efficiency

Dietary fat source did not impact final BW, ADG, ADG, or gain to feed ($P \geq 0.16$; Table 22). Increasing dietary fat level regardless of source decreased ADFI ($P = 0.001$). Increasing dietary fat level regardless of source did not impact final BW, ADG, or gain to feed ($P \geq 0.39$).

Impact of dietary fat source and inclusion level on ATTD of dietary DM, GE, and acid hydrolyzed ether extract

Dietary fat source did not impact the ATTD of dietary DM, GE, or acid hydrolyzed ether extract on d 19 ($P \geq 0.38$; Table 23). As expected, increased dietary fat inclusion level regardless of source increased the ATTD of GE and acid hydrolyzed ether extract ($P \leq 0.036$). Increasing dietary fat inclusion level did not impact ATTD of DM ($P = 0.15$).

Determination of DE content of choice white grease and corn oil

The DE content of choice white grease was determined to be 8.08 Mcal/kg via a linear regression equation using the determined DE of the control diet (with no added fat) and diets containing choice white grease fed at either 2, 4, or 6% ($P = 0.009$; $R^2 = 0.98$; Figure 1). The DE content of corn oil was determined to be 7.99 Mcal/kg via a linear regression equation using the determined DE of the control diet (with no added fat) and diets containing corn oil fed at either 2, 4, or 6% ($P = 0.024$; $R^2 = 0.95$; Figure 2).

Comparison of predicted versus observed DE values of dietary fat sources

The equation generated in Experiment 1 in 50 kg pigs (Kellner et al., 2017) had less prediction error (0.11) and bias (0.33) in predicting the DE content of the choice white grease and corn oil sources used in Experiment 2 than compared to the Powles et al. (1995) equation.

Discussion

The objective of adding fat to swine diets is to improve net income by increasing daily energy intake, thus enhancing feed efficiency and in many instances, growth rate. However, the pig's response to dietary fat is often assumed to be the same across sources, despite known chemical composition diversity. Furthermore, addition of fat to growing and finishing diets is often assumed to provide the same positive impact on growth and feed efficiency across differing environmental conditions and energy intakes. These assumptions have led to disappointment in predicting growth performance and carcass composition, ultimately resulting in overestimated financial returns for pork producers. Therefore, the overall objective of this project was to provide pork producers with accurate energy values for various dietary fat sources based on their chemical composition (free fatty acid levels, MIU content, and degree of unsaturation).

Apparent digestion of dietary fat can lead to incorrect interpretations across differing inclusion levels and intakes of dietary fat. For example, the apparent digestibility of acid hydrolyzed ether extract (used instead of the more conventional ether extract to provide a more complete extraction; Palmquist and Jenkins, 2003) is increased as inclusion of dietary fat was increased from 2% to 6% (Kellner et al., 2016). However, the increase in apparent digestibility was not due to dietary fat becoming more digestible with increased dietary concentration. The actual explanation for the increase in apparent digestibility was the dilution of endogenous losses of fat present in feces. Endogenous losses must be accounted for when comparing different inclusion levels of dietary fat. Reporting standardized or true digestibility of acid hydrolyzed ether extract allows for better comparison of results across experiments that included different levels of dietary fat.

It was found in both individually-fed pigs and group housed pigs that an unsaturated fat source (corn oil) was better digested than saturated fat sources (choice white grease and tallow; Kellner et al., 2015, 2016). Thus, this experiment was designed to discern which components of the chemical composition of dietary fats impact the digestibility of energy. Using 14 different dietary fat sources, it was determined that chemical composition of dietary fat explained ~80% of the variation observed in the energy content of dietary fat sources. The average DE content of the 14 dietary fat sources was 8.42 and 8.45 Mcal/kg at 13 kg BW and 50 kg BW, respectively. Powles et al. (1995) predicted that the average DE content of these sources would be 8.43 Mcal/kg. The Powles et al. (1995) equation has been considered the gold standard of prediction equations of dietary fat DE content and is currently used by the NRC (2012) in determining the DE, ME, and NE content of dietary fat sources. However, the observed DE values of dietary fat identified 2 potential weaknesses of the equation. The Powles et al. (1995) equation incorrectly predicted the DE content of saturated sources of dietary fat that are composed of fatty acid chain lengths < 16 carbons and underestimated the negative impact of FFA. Step-wise linear regression was utilized to explain the relationship between the chemical composition of dietary fat and the observed DE values at 13 and 50 kg BW. It was unfair to compare these equations to the Powles et al. (1995) equation within this experiment as the regression equations were fitted to the same observed DE values from which they were generated. Thus, a validation experiment was conducted under commercial conditions (Hanor Co.) to compare the equations generated Experiment 1 to those reported by Powles et al. (1995) utilizing fat sources that are independent of both studies. Using choice white grease and corn oil it was determined that the equation generated in 50 kg in Experiment 1 (Kellner et al., 2017) was more accurate and precise than the equation reported by Powles et al. (1995).

The DE system does not distinguish between fecal energy that is derived from the diet versus that of endogenous. It was found that endogenous losses of fat accounted for 43% and 68% of the acid hydrolyzed ether extract contained in feces at 13 and 50 kg BW, respectively. Thus, the digestible energy content of fat sources is underestimated when expressed on an apparent basis.

In summary, the chemical composition of dietary fat can be used to explain the variation in observed energy content. Similar to what is found in the literature, digestibility of fat sources generally decreased as the free fatty acid level increased and unsaturated to saturated fatty acid ratio decreased. However, like past experiments the exact components of the chemical composition of dietary fat that impact the digestibility and energy content of dietary fat sources were inconsistent. Use of a predictive equation (i.e., Experiment 1) that incorporates a detailed chemical composition of the dietary fat source can be used with more accuracy and precision than previous equations.

Recommendations for Future Research

Clearly, more work is needed to validate the NE estimate of dietary fat and to determine the impact of the chemical composition of dietary fat on the metabolic heat produced by the growing pig. It was also determined that approximately half of the fat contained in feces was of non-dietary origin. More work is therefore needed to determine if the DE content of dietary fat needs to be adjusted for endogenous losses.

Tables from Experiment #1

Table 1. Ingredient and nutrient composition (as-fed basis) of experimental diets d 0 to 10

	Dietary treatments[1]														
Item	CNTR	AV	CANO	CWGA	CWGB	COCO	CORA	CORB	FISH	FLAX	PALM	POUF	SOYA	SOYB	TAL
Ingredient, %															
Corn	59.90	59.90	59.90	59.90	59.90	59.90	59.90	59.90	59.90	59.90	59.90	59.90	59.90	59.90	59.90
Soybean meal (46.5% CP)	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Corn Starch	5.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Experimental dietary fat	-	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Whey, permeate	6.20	6.20	6.20	6.20	6.20	6.20	6.20	6.20	6.20	6.20	6.20	6.20	6.20	6.20	6.20
Plasma (spray-dried)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Limestone	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
Monocalcium phosphate (21%)	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-lysine HCL	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
DL-methionine	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
L-threonine	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
L-isoleucine	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
L-valine	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Trace mineral premix[2]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin premix[3]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Santoquin[4]	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Titanium dioxide	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Analyzed composition															
DM, %	88.12	88.69	88.29	88.76	89.00	88.74	88.60	88.94	88.95	88.85	88.91	88.54	89.52	88.79	88.52
GE, Mcal/kg	3.94	4.21	4.15	4.12	4.17	4.13	4.10	4.18	4.15	4.17	4.20	4.17	4.18	4.21	4.17
Acid hydrolyzed ether extract, %	2.63	8.79	8.62	7.69	8.20	8.01	7.73	8.00	8.46	8.30	8.28	8.18	8.22	8.69	8.47

[1]CNTR = control, AV = animal-vegetable blend (sourced via Darling Pro Ingredients [Wahoo, NE]), CANO = canola oil (sourced via Bulk Apothecary [Aurora, OH]), CWGA = choice white grease source A (sourced via JBS [Marshalltown, IA]), CWGB = choice

white grease source B (sourced via JBS [Worthington, MN]), COCO = coconut oil (sourced via Bulk Apothecary), CORA = corn oil source A (sourced via Feed Energy Co. [Des Moines, IA]), CORB = corn oil source B (sourced via Double S Liquid Feed Services [Danville, IL]), FISH = fish oil (sourced via Double S Liquid Feed Services), FLAX = flaxseed oil (sourced via Double S Liquid Feed Services), PALM = palm oil (sourced via Bulk Apothecary), POUF = poultry fat (sourced via Boyer Valley Co. [Denison, IA]), SOYA = soybean oil source A (sourced via Status Foods [Memphis, TN]), SOYB = soybean oil source B (sourced via Bulk Apothecary), TAL = tallow (sourced via Darling Pro Ingredients [Omaha, NE]).

[2]Provided 165 mg Zn (zinc sulfate), 165 mg Fe (iron sulfate), 39 mg Mn (manganese sulfate), 17 mg Cu (copper sulfate), 0.3 mg I (calcium iodate), and 0.3 mg Se (sodium selenite) per kilogram of diet.

[3]Provided 6,614 IU vitamin A, 827 IU vitamin D, 26 IU vitamin E, 2.6 mg vitamin K, 29.8 mg niacin, 16.5 mg pantothenic acid, 5.0 mg riboflavin, and 0.023 mg vitamin B12 per kilogram of diet.

[4]Santoquin Mixture 6 (feed and forage antioxidant; Novus International, St. Charles, MO).

Table 2. Ingredient and nutrient composition (as-fed basis) of experimental diets d 46 to 56

	Dietary treatment[1]														
Item	CNTR	AV	CANO	CWGA	CWGB	COCO	CORA	CORB	FISH	FLAX	PALM	POUF	SOYA	SOYB	TAL
Ingredient, %															
Corn	68.41	68.41	68.41	68.41	68.41	68.41	68.41	68.41	68.41	68.41	68.41	68.41	68.41	68.41	68.41
Soybean meal (46.5% CP)	22.50	22.50	22.50	22.50	22.50	22.50	22.50	22.50	22.50	22.50	22.50	22.50	22.50	22.50	22.50
Corn Starch	5.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Experimental dietary fat	-	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Limestone	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Monocalcium phosphate (21%)	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
L-lysine HCL	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
DL-methionine	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
L-threonine	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Trace mineral premix[2]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin premix[3]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Santoquin[4]	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Titanium dioxide	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Analyzed composition															
DM, %	86.66	87.35	87.43	87.68	87.64	87.77	86.79	87.41	87.61	87.83	87.36	88.02	87.07	87.27	87.45
GE, Mcal/kg	3.92	4.07	4.11	4.13	4.09	4.06	4.05	4.10	4.06	4.13	4.10	4.08	4.11	4.09	4.09
Acid hydrolyzed ether extract, %	2.97	9.32	9.56	9.32	9.07	8.94	8.55	8.92	9.14	9.51	9.02	9.20	9.59	9.56	9.21

[1]CNTR = control, AV = animal-vegetable blend (sourced via Darling Pro Ingredients [Wahoo, NE]), CANO = canola oil (sourced via Bulk Apothecary [Aurora, OH]), CWGA = choice white grease source A (sourced via JBS [Marshalltown, IA]), CWGB = choice white grease source B (sourced via JBS [Worthington, MN]), COCO = coconut oil (sourced via Bulk Apothecary), CORA = corn oil source A (sourced via Feed Energy Co. [Des Moines, IA]), CORB = corn oil source B (sourced via Double S Liquid Feed Services [Danville, IL]), FISH = fish oil (sourced via Double S Liquid Feed Services), FLAX = flaxseed oil (sourced via Double S Liquid Feed Services), PALM = palm oil (sourced via Bulk Apothecary), POUF = poultry fat (sourced via Boyer Valley Co. [Denison, IA]),

SOYA = soybean oil source A (sourced via Status Foods [Memphis, TN]), SOYB = soybean oil source B (sourced via Bulk Apothecary), TAL = tallow (sourced via Darling Pro Ingredients [Omaha, NE]).

[2]Provided 165 mg Zn (zinc sulfate), 165 mg Fe (iron sulfate), 39 mg Mn (manganese sulfate), 17 mg Cu (copper sulfate), 0.3 mg I (calcium iodate), and 0.3 mg Se (sodium selenite) per kilogram of diet.

[3]Provided 6,614 IU vitamin A, 827 IU vitamin D, 26 IU vitamin E, 2.6 mg vitamin K, 29.8 mg niacin, 16.5 mg pantothenic acid, 5.0 mg riboflavin, and 0.023 mg vitamin B12 per kilogram of diet.

[4]Santoquin Mixture 6 (feed and forage antioxidant; Novus International, St. Charles, MO).

Table 3. Ingredient and nutrient composition (as-fed basis) of experimental diets d 10 to 46[1]

Item	Common diet
Ingredient, %	
Corn	62.34
Soybean meal (46.5% CP)	31.20
Soybean oil	2.50
Limestone	0.98
Monocalcium phosphate (21%)	1.25
Salt	0.60
L-lysine HCL	0.37
DL-methionine	0.16
L-threonine	0.15
Trace mineral premix[2]	0.20
Vitamin premix[3]	0.20
Santoquin[4]	0.06
Analyzed composition	
DM, %	87.14
GE, Mcal/kg	4.02
Acid hydrolyzed ether extract, %	5.60

[1]Feed to all pigs from d 10 to 46 regardless of experiment or treatment assigned.

[2]Provided 165 mg Zn (zinc sulfate), 165 mg Fe (iron sulfate), 39 mg Mn (manganese sulfate), 17 mg Cu (copper sulfate), 0.3 mg I (calcium iodate), and 0.3 mg Se (sodium selenite) per kilogram of diet.

[3]Provided 6,614 IU vitamin A, 827 IU vitamin D, 26 IU vitamin E, 2.6 mg vitamin K, 29.8 mg niacin, 16.5 mg pantothenic acid, 5.0 mg riboflavin, and 0.023 mg vitamin B12 per kilogram of diet.

[4]Santoquin Mixture 6 (feed and forage antioxidant; Novus International, St. Charles, MO).

Table 4. Analyzed chemical composition[1] of dietary fat sources[2]

Item	AV	CANO	CWGA	CWGB	COCO	CORA	CORB	FISH	FLAX	PALM	POUF	SOYA	SOYB	TAL
Free fatty acid, %	7.00	0.03	2.00	2.00	0.08	12.80	0.28	2.80	13.40	0.08	9.20	0.02	0.02	3.60
Moisture and volatile matter, %	0.06	0.02	0.16	0.12	0.02	0.42	0.02	0.34	0.30	0.02	0.32	0.02	0.02	0.06
Insoluble impurities, %	0.02	0.02	0.04	0.02	0.02	0.02	0.14	0.06	0.02	0.02	0.02	0.02	0.02	0.06
Unsaponifiable matter, %	0.41	0.67	0.51	0.39	0.23	0.47	0.39	0.69	0.76	0.17	0.82	0.43	0.35	0.31
MIU,[3] %	0.49	0.71	0.71	0.53	0.27	0.91	0.55	1.09	1.08	0.21	1.16	0.47	0.39	0.43
Initial peroxide value, mEq/kg	0.30	0.80	7.10	9.90	0.20	0.60	0.20	13.80	4.20	1.20	1.00	2.00	0.40	1.30

[1]Analysis via Barrow Agee Laboratories (Memphis, TN).

[2]AV = animal-vegetable blend (sourced via Darling Pro Ingredients [Wahoo, NE]), CANO = canola oil (sourced via Bulk Apothecary [Aurora, OH]), CWGA = choice white grease source A (sourced via JBS [Marshalltown, IA]), CWGB = choice white grease source B (sourced via JBS [Worthington, MN]), COCO = coconut oil (sourced via Bulk Apothecary), CORA = corn oil source A (sourced via Feed Energy Co. [Des Moines, IA]), CORB = corn oil source B (sourced via Double S Liquid Feed Services [Danville, IL]), FISH = fish oil (sourced via Double S Liquid Feed Services), FLAX = flaxseed oil (sourced via Double S Liquid Feed Services), PALM = palm oil (sourced via Bulk Apothecary), POUF = poultry fat (sourced via Boyer Valley Co. [Denison, IA]), SOYA = soybean oil source A (sourced via Status Foods [Memphis, TN]), SOYB = soybean oil source B (sourced via Bulk Apothecary), TAL = tallow (sourced via Darling Pro Ingredients [Omaha, NE]).

[3]MIU = moisture, impurities, and unsaponifiables.

Table 5. Analyzed fatty acid concentrations (%)[1] of dietary fat sources[2]

Item	AV	CANO	CWGA	CWGB	COCO	CORA	CORB	FISH	FLAX	PALM	POUF	SOYA	SOYB	TAL
C5:0	ND[4]	ND	ND	ND	0.46	ND	ND	ND	ND	ND	ND	ND	ND	ND
C8:0	ND	ND	ND	ND	6.17	ND	ND	ND	ND	ND	ND	ND	ND	ND
C10:0	ND	ND	ND	ND	5.39	ND	ND	ND	ND	ND	ND	ND	ND	ND
C12:0	ND	ND	ND	ND	48.46	ND	ND	0.11	ND	0.19	ND	ND	ND	ND
C14:0	1.63	ND	1.31	1.33	19.75	ND	0.07	9.88	ND	1.03	0.74	0.07	0.07	2.78
C14:1	0.21	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.14	ND	ND	0.54
C15:0	0.14	ND	ND	ND	ND	ND	ND	0.73	ND	ND	ND	ND	ND	0.43
C16:0	22.39	4.16	22.47	22.35	9.44	11.92	10.60	20.33	5.20	44.19	18.89	10.79	10.55	24.08
C16:1	2.92	0.20	2.49	2.52	ND	0.09	0.08	11.66	ND	0.15	3.99	0.08	0.08	2.48
C16:2	ND	ND	ND	ND	ND	ND	ND	1.43	ND	ND	ND	ND	ND	ND
C17:0	0.46	ND	0.33	0.33	ND	ND	0.11	0.82	ND	0.10	0.24	0.10	0.10	1.22
C17:1	0.41	0.15	ND	ND	ND	ND	ND	0.25	ND	ND	ND	ND	ND	ND
C18:0	10.45	1.80	11.21	10.97	9.08	1.71	4.30	3.49	3.20	4.47	6.31	3.78	3.78	20.29
C18:1	45.25	63.36	42.15	42.34	1.07	27.20	22.94	9.28	17.00	39.42	34.53	22.00	23.50	41.59
C18:2	13.41	19.28	16.54	16.72	0.06	56.84	53.37	1.15	14.90	9.52	31.78	54.19	52.27	2.81
C18:3	0.62	8.41	0.60	0.60	ND	1.35	7.61	1.34	59.60	0.19	2.06	7.84	8.14	0.31
C18:4	ND	ND	ND	ND	ND	ND	ND	2.01	ND	ND	ND	ND	ND	ND
C19:0	ND	ND	ND	ND	ND	ND	0.11	ND	0.20	ND	ND	ND	ND	ND
C19:1	ND	0.36	ND	ND	ND	ND	ND	0.42	ND	ND	ND	ND	ND	0.11
C20:0	0.15	0.58	0.16	0.16	0.12	0.36	0.31	0.24	ND	0.36	ND	0.28	0.27	0.12
C20:1	0.67	1.10	0.82	0.83	ND	0.26	0.18	0.86	ND	0.13	0.25	0.17	0.17	0.23
C20:2	0.57	ND	0.83	0.84	ND	ND	ND	0.20	ND	ND	0.23	ND	ND	ND
C20:3	ND	ND	0.13	0.13	ND	ND	ND	1.36	ND	ND	0.62	ND	ND	ND
C20:4	0.24	ND	0.36	0.36	ND	ND	ND	1.36	ND	ND	0.62	ND	ND	ND
C20:5	ND	ND	ND	ND	ND	ND	ND	14.32	ND	ND	ND	ND	ND	ND
C22:0	ND	0.31	ND	ND	ND	0.13	0.34	0.16	ND	ND	ND	0.33	0.32	ND
C22:1	ND	ND	ND	ND	ND	ND	ND	0.10	ND	ND	ND	ND	ND	ND
C22:3	ND	ND	ND	ND	ND	ND	ND	0.40	ND	ND	ND	ND	ND	ND
C22:4	ND	ND	0.17	0.16	ND	ND	ND	0.23	ND	ND	ND	ND	ND	ND
C22:5	ND	0.15	ND	ND	ND	0.16	ND	2.81	ND	ND	ND	ND	ND	ND
C22:6	ND	ND	ND	ND	ND	ND	ND	8.22	ND	ND	ND	ND	ND	ND
C24:1	ND	0.13	ND	ND	ND	ND	ND	0.25	ND	ND	ND	ND	ND	ND
Other	0.46	ND	0.36	0.35	ND	ND	ND	7.56	ND	0.23	0.23	0.13	0.14	3.01

[1]Analysis via Barrow Agee Laboratories (Memphis, TN).

[2]AV = animal-vegetable blend (sourced via Darling Pro Ingredients [Wahoo, NE]), CANO = canola oil (sourced via Bulk Apothecary [Aurora, OH]), CWGA = choice white grease source A (sourced via JBS [Marshalltown, IA]), CWGB = choice white grease source B (sourced via JBS [Worthington, MN]), COCO = coconut oil (sourced via Bulk Apothecary), CORA = corn oil source

A (sourced via Feed Energy Co. [Des Moines, IA]), CORB = corn oil source B (sourced via Double S Liquid Feed Services [Danville, IL]), FISH = fish oil (sourced via Double S Liquid Feed Services), FLAX = flaxseed oil (sourced via Double S Liquid Feed Services), PALM = palm oil (sourced via Bulk Apothecary), POUF = poultry fat (sourced via Boyer Valley Co. [Denison, IA]), SOYA = soybean oil source A (sourced via Status Foods [Memphis, TN]), SOYB = soybean oil source B (sourced via Bulk Apothecary), TAL = tallow (sourced via Darling Pro Ingredients [Omaha, NE]).

[3]Valeric acid (C5:0), caproic acid (C8:0), capric acid (C10:0), lauric acid (C12:0), myristic acid (C14:0), myristoleic acid (C14:1), pentadecanoic acid (C15:0), palmitic acid (C16:0), palmitoleic acid (C16:1), hexadecadienoic acid (C16:2), margaric acid (C17:0), margaroleic acid (C17:1), stearic acid (C18:0), oleic acid (C18:1), linoleic acid (C18:2), linolenic acid (C18:3), octadecatetraenoic acid (C18:4), nonadecenoic acid (C19:1), arachidic acid (C20:0), gadoleic acid (C20:1), eicosadienoic acid (C20:2), homo-γ linolenic acid (20:3), arachidonic acid (C20:4), eicosapentaenoic acid (C20:5), behenic acid (C22:0), erucic acid (C22:1), docosatrienoic acid (C22:3), docosatetraenoic acid (C22:4), docosapentaenoic acid (C22:5), docosahexaenoic acid (C22:6), nervonic acid (C24:1).

[4]ND = non-detectable.

Table 6. Analyzed fatty acid composition and characteristics[1] of dietary fat sources[2]

Item	AV	CANO	CWGA	CWGB	COCO	CORA	CORB	FISH	FLAX	PALM	POUF	SOYA	SOYB	TAL
Omega-3, %	0.62	8.56	0.73	0.73	0.00	1.51	7.61	29.08	59.60	0.19	2.06	7.84	8.14	0.31
Omega-6, %	14.22	19.28	17.90	18.08	0.06	56.84	53.37	2.94	14.90	9.52	32.63	54.19	52.57	2.81
Omega-6:Omega-3	22.94	2.25	24.52	24.77	NC	37.64	7.10	0.10	0.25	50.11	15.84	6.91	6.46	9.06
MUFA, %	49.46	65.30	45.46	45.69	1.07	27.55	23.20	22.82	17.00	39.70	38.91	22.25	23.75	44.95
PUFA, %	14.84	27.84	18.63	18.81	0.06	58.35	60.98	33.85	74.40	9.71	34.69	62.03	60.71	3.12
SFA, %	35.22	6.85	35.36	35.14	98.87	14.12	15.84	35.76	8.60	50.34	26.18	15.59	15.39	48.92
MUFA:PUFA	3.33	2.35	2.44	2.43	17.83	0.47	0.38	0.67	0.23	4.09	1.12	0.36	0.39	14.41
MUFA:SFA	1.40	9.53	1.28	1.30	0.01	1.95	1.46	0.64	1.97	0.79	1.49	1.43	1.54	0.92
PUFA:SFA	0.42	4.06	0.52	0.54	0.00	4.13	3.85	0.95	8.66	0.19	1.33	3.98	3.94	0.06
IV[3], g/ 100 g	68.7	111.5	72.7	73.2	1.0	126.3	132.3	137.4	196.2	51.1	96.5	133.5	132.8	44.0
U:S[4]	1.83	13.60	1.80	1.84	0.01	6.08	5.31	1.58	10.63	0.98	2.81	5.41	5.49	0.98

[1]Analysis via Barrow Agee Laboratories (Memphis, TN).

[2]AV = animal-vegetable blend (sourced via Darling Pro Ingredients [Wahoo, NE]), CANO = canola oil (sourced via Bulk Apothecary [Aurora, OH]), CWGA = choice white grease source A (sourced via JBS [Marshalltown, IA]), CWGB = choice white grease source B (sourced via JBS [Worthington, MN]), COCO = coconut oil (sourced via Bulk Apothecary), CORA = corn oil source A (sourced via Feed Energy Co. [Des Moines, IA]), CORB = corn oil source B (sourced via Double S Liquid Feed Services [Danville, IL]), FISH = fish oil (sourced via Double S Liquid Feed Services), FLAX = flaxseed oil (sourced via Double S Liquid Feed Services), PALM = palm oil (sourced via Bulk Apothecary), POUF = poultry fat (sourced via Boyer Valley Co. [Denison, IA]), SOYA = soybean oil source A (sourced via Status Foods [Memphis, TN]), SOYB = soybean oil source B (sourced via Bulk Apothecary), TAL = tallow (sourced via Darling Pro Ingredients [Omaha, NE]).

[3]Iodine value calculated from fatty acid composition: (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.795 + [C20:2] × 1.57 + [C20:3] × 2.38 + [C20:4] × 3.19 + [C20:5] × 4.01 + [C22:4] × 2.93 + [C22:5] × 3.68 + [C22:6] × 4.64; brackets indicate percentage concentration (Meadus et al., 2010).

[4]U:S = unsaturated fatty acid concentration to SFA concentration.

Table 7. Determination of DE, ME and NE content of dietary fat sources (Mcal/kg; as-fed basis) based on the apparent total tract digestion of GE at 13 kg BW[1]

	Dietary treatment[2]																
Item	CNTR	AV	CANO	CWGA	CWGB	COCO	CORA	CORB	FISH	FLAX	PALM	POUF	SOYA	SOYB	TAL	SEM	*P*-value
Diet (Mcal/kg)																	
GE	3.94	4.21	4.15	4.12	4.17	4.13	4.10	4.18	4.15	4.17	4.20	4.17	4.18	4.21	4.17	-	-
DE	3.70^{f}	3.94^{ab}	3.93^{abc}	3.91^{bcd}	3.93^{abc}	3.88^{d}	3.84^{e}	3.92^{abc}	3.93^{abc}	3.90^{cd}	3.94^{ab}	3.93^{abc}	3.95^{a}	3.95^{ab}	3.91^{bcd}	0.01	<0.001
Dietary fat (Mcal/kg)																	
DE[3]	-	8.81^{abc}	8.59^{abc}	8.32^{bcd}	8.67^{abc}	7.65^{d}	6.90^{e}	8.52^{abc}	8.69^{abc}	8.06^{cd}	8.81^{ab}	8.67^{abc}	9.04^{a}	8.99^{ab}	8.33^{bcd}	0.25	<0.001
ME[4]	-	8.63^{abc}	8.42^{abc}	8.15^{bcd}	8.49^{abc}	7.49^{d}	6.58^{e}	8.35^{abc}	8.52^{abc}	7.90^{cd}	8.63^{ab}	8.49^{abc}	8.86^{a}	8.81^{ab}	8.16^{bcd}	0.24	<0.001
NE[5]	-	7.59^{abc}	7.41^{abc}	7.17^{bcd}	7.47^{abc}	6.59^{d}	5.95^{e}	7.35^{abc}	7.50^{abc}	6.95^{cd}	7.60^{ab}	7.47^{abc}	7.80^{a}	7.76^{ab}	7.18^{bcd}	0.21	<0.001

[1]Determined via 120 pigs (8 pigs/treatment) with a d 7 BW of 12.3 ± 0.2 kg and a d 10 BW of 13.8 ± 0.4 kg.

[2]Each experimental diet included 95% of a corn-soybean meal basal diet and then 5% of either: corn starch (CNTR), animal-vegetable blend (AV), canola oil (CANO), choice white grease source A (CWGA), choice white grease source B (CWGB), coconut oil (COCO), corn oil source A (CORA), corn oil source B (CORB), fish oil (FISH), flaxseed oil (FLAX), palm oil (PALM), poultry fat (POUF), soybean oil source A (SOYA), soybean oil source B (SOYB), or tallow (TAL).

[3]$DE_{\text{dietary fat}}$ (Mcal/kg) = {$DE_{\text{test diet}}$ – [$DE_{\text{basal diet}}$ (3.68 Mcal/kg) × (1 – proportion of dietary fat in the diet; 5%)]}/proportion of dietary fat in the diet; 5% (Villamide, 1996).

[4]$ME_{\text{dietary fat}}$ (Mcal/kg) = DE × 98% (van Milgen et al., 2001; NRC, 2012).

[5]$NE_{\text{dietary fat}}$ (Mcal/kg) = ME × 88% (van Milgen et al., 2001; NRC, 2012).

Table 8. Determination of DE, ME and NE content of dietary fat sources (Mcal/kg; as-fed basis) based on the apparent total tract digestion of GE at 50 kg BW[1]

Item	Dietary treatment[2]															SEM	*P*-value
	CNTR	AV	CANO	CWGA	CWGB	COCO	CORA	CORB	FISH	FLAX	PALM	POUF	SOYA	SOYB	TAL		
Diet (Mcal/kg)																	
GE	3.89	4.07	4.11	4.13	4.09	4.06	4.05	4.10	4.06	4.13	4.10	4.08	4.11	4.09	4.09	-	-
DE	3.65^{i}	3.81^{h}	3.92^{a}	3.91^{ab}	3.88^{cd}	3.84^{fgh}	3.81^{h}	3.87^{cde}	3.83^{gh}	3.91^{ab}	3.86^{cdef}	3.85^{efg}	3.89^{abc}	3.85^{defg}	3.85^{defg}	0.02	<0.001
Dietary fat (Mcal/kg)																	
DE[3]	-	7.51^{g}	9.53^{a}	9.31^{a}	8.72^{bc}	7.97^{efg}	7.43^{g}	8.55^{bcd}	7.77^{fg}	9.43^{a}	8.50^{bcde}	8.14^{def}	9.05^{ab}	8.18^{cdef}	8.22^{cdef}	0.31	<0.001
ME[4]	-	7.36^{g}	9.34^{a}	9.12^{a}	8.55^{bc}	7.81^{efg}	7.28^{g}	8.38^{bcd}	7.61^{fg}	9.24^{a}	8.33^{bcde}	7.97^{def}	8.87^{ab}	8.02^{cdef}	8.05^{cdef}	0.31	<0.001
NE[5]	-	6.48^{g}	8.22^{a}	8.03^{a}	7.52^{bc}	6.87^{efg}	6.41^{g}	7.38^{bcd}	6.70^{fg}	8.13^{a}	7.33^{bcde}	7.02^{def}	7.80^{ab}	7.06^{cdef}	7.09^{cdef}	0.27	<0.001

[1]Determined via 120 pigs (8 pigs/treatment) with a d 53 BW of 49.1 ± 2.2 kg and a d 56 BW of 51.7 ± 1.7 kg.

[2]Each experimental diet included 95% of a corn-soybean meal basal diet and then 5% of either: corn starch (CNTR), animal-vegetable blend (AV), canola oil (CANO), choice white grease source A (CWGA), choice white grease source B (CWGB), coconut oil (COCO), corn oil source A (CORA), corn oil source B (CORB), fish oil (FISH), flaxseed oil (FLAX), palm oil (PALM), poultry fat (POUF), soybean oil source A (SOYA), soybean oil source B (SOYB), or tallow (TAL).

[3]$DE_{\text{dietary fat}}$ (Mcal/kg) = {$DE_{\text{test diet}}$ – [$DE_{\text{basal diet}}$ (3.62 Mcal/kg) × (1 – proportion of dietary fat in the diet; 5%)]}/proportion of dietary fat in the diet; 5% (Villamide, 1996).

[4]$ME_{\text{dietary fat}}$ (Mcal/kg) = DE × 98% (van Milgen et al., 2001; NRC, 2012).

[5]$NE_{\text{dietary fat}}$ (Mcal/kg) = ME × 88% (van Milgen et al., 2001; NRC, 2012).

Table 9. Correlation coefficients (r) between dietary fatty acid composition and estimated dietary fat DE content (Mcal/kg)

	Dietary fat DE (Mcal/kg)	
Item	13 kg[1]	50 kg[2]
Fatty acid[3], %		
Linoleic acid (C18:3)	NS[7]	0.489*
Omega-3, %	NS	NS
Omega-6, %	NS	NS
Omega-6:Omega-3	-0.468*	NS
MUFA, %	NS	NS
PUFA, %	NS	NS
SFA, %	NS	NS
MUFA:PUFA	NS	NS
MUFA:SFA	NS	0.483*
PUFA:SFA	NS	NS
IV, (Meadus, 2010)[4] g/ 100 g	NS	NS
U:S[5]	NS	0.549**
Free fatty acid, %	-0.530*	NS
Moisture and volatile matter, %	-0.498*	NS
Insoluble impurities, %	NS	NS
Unsaponifiable matter, %	NS	NS
MIU,[6] %	NS	NS
Initial peroxide value, mEq/kg	NS	NS

*Probability value of obtaining the observed coefficient ($P \leq 0.100 \geq 0.050$).

**Probability value of obtaining the observed coefficient ($P \leq 0.050$).

[1]Determined via 120 pigs (8 pigs/treatment) with a d 7 BW of 12.3 ± 0.2 kg and a d 10 BW of 13.8 ± 0.4 kg.

[2]Determined via 120 pigs (8 pigs/treatment) with a d 53 BW of 49.1 ± 2.2 kg and a d 56 BW of 51.7 ± 1.7 kg.

[3]Other than linoleic acid (C18:3, %), no other dietary fatty acid concentrations were correlated with the DE content of dietary fat ($P \geq 0.101$).

[4]Iodine value calculated from fatty acid composition: (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.795 + [C20:2] × 1.57 + [C20:3] × 2.38 + [C20:4] × 3.19 + [C20:5] × 4.01 + [C22:4] × 2.93 + [C22:5] × 3.68 + [C22:6] × 4.64; brackets indicate percentage concentration (Meadus et al., 2010).

[5]Unsaturated fatty acid concentration to SFA concentration.

[6]MIU = moisture, impurities, and unsaponifiables.

[7]NS = non-significant ($P > 0.100$).

Table 10. Relationship between dietary fat DE, ME and NE (Mcal/kg; as-fed basis) content and chemical composition[1] of dietary fat source as determined via stepwise regression analysis

Item	Equation	Mean square error	R^2	*P*-value
13 kg[2]				
DE	= 8.671 – [0.063 × (FFA)]	0.258	0.282	0.051
	= 8.967 – [0.073 × (FFA)] – [0.012 × Omega-6:Omega-3]	0.164	0.581	0.008
	= 9.353 – [0.092 × (FFA)] – [0.013 × Omega-6:Omega-3] – [1.290 × (C20:0)]	0.140	0.675	0.008
	= 9.656 – [0.104 × (FFA)] – [0.015 × Omega-6:Omega-3] – [1.389 × (C20:0)] – [5.294 × (INIM)]	0.118	0.755	0.008
	= 9.363 – [0.097 × (FFA)] – [0.016 × Omega-6:Omega-3] – [1.240 × (C20:0)] – [5.054 × (INIM)] + [0.014 × (C16:0)]	0.099	0.815	0.008
ME	= 8.498 – [0.062 × (FFA)]	0.248	0.282	0.051
	= 8.787 – [0.071 × (FFA)] – [0.012 × Omega-6:Omega-3]	0.157	0.581	0.008
	= 9.353 – [0.090 × (FFA)] – [0.013 × Omega-6:Omega-3] – [1.265 × (C20:0)]	0.135	0.675	0.008
	= 9.463 – [0.102 × (FFA)] – [0.015 × Omega-6:Omega-3] – [1.361 × (C20:0)] – [5.188 × (INIM)]	0.113	0.755	0.008
	= 9.176 – [0.095 × (FFA)] – [0.016 × Omega-6:Omega-3] – [1.215 × (C20:0)] – [4.953 × (INIM)] + [0.014 × (C16:0)]	0.096	0.815	0.008
NE	= 7.478 – [0.055 × (FFA)]	0.192	0.282	0.051
	= 7.732 – [0.063 × (FFA)] – [0.010 × Omega-6:Omega-3]	0.122	0.581	0.008
	= 8.066 – [0.079 × (FFA)] – [0.011 × Omega-6:Omega-3] – [1.113 × (C20:0)]	0.104	0.675	0.008
	= 8.327 – [0.089 × (FFA)] – [0.013 × Omega-6:Omega-3] – [1.198 × (C20:0)] – [4.566 × (INIM)]	0.087	0.755	0.008
	= 8.075 – [0.093 × (FFA)] – [0.014 × Omega-6:Omega-3] – [1.070 × (C20:0)] – [4.359 × (INIM)] + [0.013 × (C16:0)]	0.074	0.815	0.008
50 kg[3]				
DE	= 8.050 + [0.096 × U:S]	0.358	0.302	0.042
	= 8.190 + [0.110 × U:S] – [0.052 × (FFA)]	0.319	0.429	0.046
	= 8.439 + [0.189 × U:S] – [0.107 × (FFA)] – [3.232 × (C22:0)]	0.222	0.639	0.014
	= 8.357 + [0.189 × U:S] – [0.195 × (FFA)] – [6.768 × (C22:0)] + [0.024 × (PUFA)]	0.128	0.813	0.003
ME	= 7.889 + [0.094 × U:S]	0.344	0.302	0.042
	= 8.026 + [0.108 × U:S] – [0.052 × (FFA)]	0.307	0.429	0.046
	= 8.270 + [0.185 × U:S] – [0.105 × (FFA)] – [3.168 × (C22:0)]	0.217	0.639	0.014
	= 8.190 + [0.185 × U:S] – [0.191 × (FFA)] – [6.633 × (C22:0)] + [0.023 × (PUFA)]	0.123	0.813	0.003
NE	= 6.942 + [0.083 × U:S]	0.266	0.302	0.042
	= 7.063 + [0.095 × U:S] – [0.045 × (FFA)]	0.237	0.429	0.046
	= 7.277 + [0.163 × U:S] – [0.092 × (FFA)] – [2.787 × (C22:0)]	0.165	0.639	0.014
	= 7.207 + [0.163 × U:S] – [0.168 × (FFA)] – [5.836 × (C22:0)] + [0.021 × (PUFA)]	0.095	0.813	0.003

[1]C16:0 = palmitic acid (%); C20:0 =arachidic acid (%); C22:0 = behenic acid (%); FFA = free fatty acid (%); INIM = insoluble impurities (%); U:S = unsaturated to saturated fatty acid ratio; parenthesis indicate concentration (%).

[2]Determined via 120 pigs (8 pigs/treatment) with a d 7 BW of 12.3 ± 0.2 kg and a d 10 BW of 13.8 ± 0.4 kg.

[3]Determined via 120 pigs (8 pigs/treatment) with a d 53 BW of 49.1 ± 2.2 kg and a d 56 BW of 51.7 ± 1.7 kg.

Table 11. Comparison of predicted versus observed DE (Mcal/kg) values at 13 kg

Item	Observed DE[1]	Powles et al. (1995) predicted DE[2]	Δ DE[3]	Predicted DE[4]	Δ DE
Source					
Animal-vegetable blend	8.81	8.40	-0.41	8.34	-0.46
Canola oil	8.59	8.82	0.23	8.56	-0.02
Choice white grease source A	8.32	8.45	0.13	8.69	0.37
Choice white grease source B	8.67	8.46	-0.21	8.79	0.12
Coconut oil	7.65	7.08	-0.56	7.64	-0.01
Corn oil source A	6.90	8.66	1.76	7.14	0.24
Corn oil source B	8.52	8.80	0.28	8.28	-0.24
Fish oil	8.69	8.37	-0.32	8.78	0.08
Flax oil	8.06	8.66	0.60	8.03	-0.03
Palm oil	8.81	8.10	-0.71	8.62	-0.18
Poultry fat	8.67	8.57	-0.10	8.38	-0.28
Soybean oil source A	9.04	8.81	-0.23	8.95	-0.08
Soybean oil source B	8.99	8.81	-0.18	8.97	-0.02
Tallow	8.33	8.06	-0.27	8.76	0.43
Predication error[5]	-	1.60	-	0.68	-
Prediction bias[6]	-	0.01	-	-0.01	-

[1]Determined via 120 pigs (8 pigs/treatment) with a d 7 BW of 12.3 ± 0.2 kg and a d 10 BW of 13.8 ± 0.4 kg.

[2]DE (kcal/kg) = [36.898 – (0.005 × free fatty acid, g/kg) – 7.330 × $e^{-0.906 \times \text{unsaturated fatty acid to SFA ratio}}$)]/0.004184 (Powles et al., 1995); refer to table 5 and 6 for dietary fatty acid and chemical composition.

[3]Delta DE (Mcal/kg) = predicted DE (Mcal/kg) – observed DE (Mcal/kg).

[4]DE (Mcal/kg) = 9.363 – [0.097 × FFA, %] – [0.016 × Omega-6:Omega-3] – [1.240 × arachidic acid, %] – [5.054 × insoluble impurities, %] + [0.014 × palmitic acid, %]; refer to table 10.

[5]Prediction error = √ [(1/number of dietary fat treatments) × Σ (absolute differences between predicted and observed energy values)^2] (Lane et al., 2014).

[6]Prediciton bias = [(1/number of dietary fat treatments) × Σ (difference between predicted and observed energy values)] (smaller absolute value indicates greater accuracy of the equation; negative value indicates underestimation and positive value indicates overestimation; Lane et al., 2014).

Table 12. Comparison of predicted versus observed DE (Mcal/kg) values at 50 kg

Item	Observed DE[1]	Powles et al. (1995) predicted DE[2]	Δ DE[3]	Predicted DE[4]	Δ DE
Source					
Animal-vegetable blend	7.51	8.40	0.89	7.69	0.19
Canola oil	9.53	8.82	-0.71	9.52	-0.01
Choice white grease source A	9.31	8.45	-0.86	8.75	-0.56
Choice white grease source B	8.72	8.46	-0.26	8.77	0.04
Coconut oil	7.97	7.08	-0.89	8.34	0.38
Corn oil source A	7.43	8.66	1.23	7.54	0.11
Corn oil source B	8.55	8.80	0.25	8.50	-0.05
Fish oil	7.77	8.37	0.60	7.85	0.09
Flax oil	9.43	8.66	-0.77	9.54	0.11
Palm oil	8.50	8.10	-0.40	8.76	0.26
Poultry fat	8.14	8.57	0.43	7.93	-0.21
Soybean oil source A	9.05	8.81	-0.24	8.66	-0.39
Soybean oil source B	8.18	8.81	0.63	8.71	0.53
Tallow	8.22	8.06	-0.16	7.92	-0.30
Predication error[5]	-	2.22	-	0.86	-
Prediction bias[6]	-	-0.02	-	0.01	-

[1]Determined via 120 pigs (8 pigs/treatment) with a d 53 BW of 49.1 ± 2.2 kg and a d 56 BW of 51.7 ± 1.7 kg.

[2]DE (kcal/kg) = [36.898 – (0.005 × free fatty acid, g/kg) – 7.330 × $^{e-0.906 \times \text{unsaturated fatty acid to SFA ratio}}$)]/0.004184 (Powles et al., 1995); refer to table 5 and 6 for dietary fatty acid and chemical composition.

[3]Delta DE (Mcal/kg) = predicted DE (Mcal/kg) – observed DE (Mcal/kg).

[4]DE (Mcal/kg) = 8.357 + [0.189 × unsaturated fatty acid:SFA] – [0.195 × FFA, %] – [6.768 × behenic acid, %] + [0.024 × PUFA, %]; refer to table 10.

[5]Prediction error = √ [(1/number of dietary fat treatments) × Σ (absolute differences between predicted and observed energy values)^2] (Lane et al., 2014).

[6]Prediciton bias = [(1/number of dietary fat treatments) × Σ (difference between predicted and observed energy values)] (smaller absolute value indicates greater accuracy of the equation; negative value indicates underestimation and positive value indicates overestimation; Lane et al., 2014).

Table 13. Ingredient and nutrient composition (as-fed basis) of fat-free experimental diets d 0 to 10 and d 46 to 56

Item	d 0 to 10	d 46 to 56
Ingredient, %		
Corn starch	76.96	78.53
Sucrose	10.00	10.00
Solka Floc	3.00	3.00
L-lysine HCL	1.65	1.25
DL-methionine	0.75	0.57
L-threonine	0.80	0.62
L-tryptophan	0.22	0.17
L-isoleucine	0.72	0.54
L-valine	0.86	0.66
Monocalcium phosphate (21%)	1.90	1.80
Limestone	0.97	0.92
Salt	0.68	0.50
Potassium carbonate	0.50	0.45
Magnesium oxide	0.02	-
Trace mineral premix[2]	0.20	0.20
Vitamin premix[3]	0.31	0.31
Santoquin[4]	0.06	0.06
Titanium dioxide	0.40	0.40
Analyzed composition		
DM, %	92.01	91.53
Acid hydrolyzed ether extract, %	0.18	0.28

[1]Feed to all pigs from d 10 to 46 regardless of treatment assigned.

[2]Provided 165 mg Zn (zinc sulfate), 165 mg Fe (iron sulfate), 39 mg Mn (manganese sulfate), 17 mg Cu (copper sulfate), 0.3 mg I (calcium iodate), and 0.3 mg Se (sodium selenite) per kilogram of diet.

[3]Provided 6,614 IU vitamin A, 827 IU vitamin D, 26 IU vitamin E, 2.6 mg vitamin K, 29.8 mg niacin, 16.5 mg pantothenic acid, 5.0 mg riboflavin, and 0.023 mg vitamin B12 per kilogram of diet.

[4]Santoquin Mixture 6 (feed and forage antioxidant; Novus International, St. Charles, MO).

Table 14. Least square means of the estimated endogenous losses of dietary fat digestion (ELF) across the total tract

Item	Estimated ELF, g/kg of DM intake[1]	*P*-value
9 kg BW[2]	4.17 ± 0.69	<0.001
38 kg BW[3]	6.67 ± 1.11	0.002

[1]Estimate of ELF was determined by the following equation: ELF = [g of acid hydrolyzed ether extract/kg of feces (dry matter basis)] - [g of acid hydrolyzed ether extract/kg of feed (dry matter basis)].

[2]Determined via 8 pigs with a d 7 BW of 9.1 ± 0.6 kg and a d 10 BW of 9.2 ± 0.6 kg.

[3]Determined via 8 pigs with a d 53 BW of 37.6 ± 2.1 kg and a d 56 BW of 37.6 ± 2.2 kg.

Table 15. Effects of dietary fat source on apparent total tract digestibility (ATTD) of acid hydrolysis ether extract (AEE)[1], and standardized total tract digestibility (STTD)[2] of dietary AEE at 13 and 50 kg BW

	Dietary treatment[3]																
Item	CNTR	AV	CANO	CWGA	CWGB	COCO	CORA	CORB	FISH	FLAX	PALM	POUF	SOYA	SOYB	TAL	SEM	*P*-value
13 kg BW[3]																	
ATTD of AEE, %	74.0[d]	89.0[abc]	90.8[a]	90.2[ab]	90.0[ab]	89.6[abc]	88.1[bc]	88.3[bc]	91.0[a]	88.2[bc]	87.7[c]	89.7[abc]	89.4[abc]	89.3[abc]	87.7[c]	0.8	<0.001
STTD of AEE,[4] %	88.0[e]	93.3[abcd]	95.1[ab]	95.0[ab]	94.5[abc]	94.2[abcd]	92.9[bcd]	93.0[bcd]	95.4[a]	92.7[cd]	92.2[d]	94.1[abcd]	94.0[abcd]	93.6[abcd]	92.1[d]	0.8	<0.001
50 kg BW[5]																	
ATTD of AEE, %	73.5[e]	89.5[c]	92.5[a]	90.8[abc]	91.7[ab]	90.5[bc]	87.6[d]	90.0[bc]	91.1[abc]	91.5[ab]	89.4[c]	90.4[bc]	91.7[ab]	90.4[bc]	89.4[c]	1.0	<0.001
STTD of AEE,[6] %	93.0[g]	95.8[def]	98.6[a]	97.1[abcde]	98.2[ab]	97.0[abcde]	94.3[f]	96.6[bcde]	97.5[abcd]	97.7[abc]	95.9[cdef]	96.8[abcde]	97.7[abc]	96.5[bcde]	95.7[ef]	1.0	<0.001

[1]Apparent total tract digestibility (ATTD; %) of AEE was calculated as 100 – {100 × [concentration (g) of TiO_2 in diet × concentration of (g) of AEE in feces]/[concentration (g) of TiO_2 in feces × concentration of AEE in diet]}; (Oresanya et al. 2007).

[2]Calculated as ATTD of AEE (%) + {[ELF (g/kg of DM intake)/concentration (g) of AEE in diet] × 100} (Stein et al., 2007).

[3]Each experimental diet included 95% of a corn-soybean meal basal diet and then 5% of either: corn starch (CNTR), animal-vegetable blend (AV), canola oil (CANO), choice white grease source A (CWGA), choice white grease source B (CWGB), coconut oil (COCO), corn oil source A (CORA), corn oil source B (CORB), fish oil (FISH), flaxseed oil (FLAX), palm oil (PALM), poultry fat (POUF), soybean oil source A (SOYA), soybean oil source B (SOYB), or tallow (TAL).

[4]Determined via 120 pigs (8 pigs/treatment) with a d 7 BW of 12.3 ± 0.2 kg and a d 10 BW of 13.8 ± 0.4 kg.

[5]Calculated by correcting ATTD of AEE (%) for endogenous losses estimated at 4.17 g/kg of DM intake.

[6]Determined via 120 pigs (8 pigs/treatment) with a d 53 BW of 49.1 ± 2.2 kg and a d 56 BW of 51.7 ± 1.7 kg.

[7]Calculated by correcting ATTD of AEE (%) for endogenous losses estimated at 6.67 g/kg of DM intake.

Table 16. Effects of dietary fat source on intake, disappearance, and fecal excretion of acid hydrolyzed ether extract (AEE; g/kg of DM intake) from d 7 to 10 and d 53 to 56

	Dietary treatment[3]																
Item	CNTR	AV	CANO	CWGA	CWGB	COCO	CORA	CORB	FISH	FLAX	PALM	POUF	SOYA	SOYB	TAL	SEM	*P*-value
d 7 to 10																	
Intake	29.8	99.1	97.6	86.6	92.1	90.2	87.3	89.9	95.1	93.5	93.1	92.4	91.8	97.9	95.6	-	-
TTD[1]	22.1^{i}	88.2^{ab}	88.6^{a}	78.1^{gh}	82.9^{cd}	80.8^{ef}	76.9^{h}	79.4^{fg}	86.6^{b}	82.4^{cde}	81.7^{de}	82.8^{cde}	82.1^{cde}	87.4^{ab}	83.9^{c}	0.7	<0.001
TFE[2]	7.7^{f}	10.9^{abcd}	9.0^{def}	8.5^{ef}	9.2^{cdef}	9.4^{cdef}	10.4^{abcde}	10.5^{abcde}	8.5^{ef}	11.0^{abc}	11.5^{ab}	9.6^{bcdef}	9.7^{bcdef}	10.5^{abcde}	11.7^{a}	0.7	0.002
ELF[3] in feces	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	-	-
Non-ELF in feces[4]	3.6^{f}	6.7^{abcd}	4.8^{def}	4.3^{ef}	5.1^{cdef}	5.2^{cdef}	6.2^{abcde}	6.4^{abcde}	4.4^{ef}	6.8^{abc}	7.3^{de}	5.4^{cde}	5.5^{cde}	6.3^{ab}	7.6^{a}	0.7	0.002
d 7 to 10																	
Intake	34.2	106.7	109.4	106.3	103.5	101.9	98.6	102.0	104.3	108.3	103.3	104.5	110.1	109.5	105.4	-	-
TTD[1]	25.2^{g}	95.6^{cd}	101.1^{a}	96.5^{d}	94.9^{d}	92.1^{e}	86.3^{f}	91.9^{e}	94.9^{d}	99.1^{b}	92.3^{e}	94.5^{d}	101.0^{a}	99.0^{b}	94.2^{d}	1.0	<0.001
TFE[2]	9.1^{cde}	11.2^{ab}	8.2^{e}	9.8^{bcde}	8.6^{d}	9.7^{bcde}	12.3^{a}	10.2^{bc}	9.3^{cde}	9.2^{cde}	10.9^{ab}	10.1^{bcd}	9.2^{cde}	10.5^{bc}	11.2^{ab}	1.0	<0.001
ELF[3] in feces	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	-	-
Non-ELF in feces4	2.4^{cde}	4.5^{ab}	1.6^{e}	3.1^{bcde}	1.9^{d}	3.1^{bcde}	5.6^{a}	3.5^{bc}	2.7^{cde}	2.5^{cde}	4.3^{ab}	3.4^{bcd}	2.5^{cde}	3.8^{bc}	4.5^{ab}	1.0	<0.001

[1]Total tract disappearance (g/kg of DM intake) = intake – total amount of AEE in feces.

[2]Total fecal excretion

[2]Basal endogenous losses of fat digestion (g/kg of DM intake).

[3]Amount of AEE from non-ELF origin (g/kg of DM intake) was calculated as total amount of AEE in feces – ELF in feces.

Table 17. Determination of DE, ME and NE content of dietary fat sources (Mcal/kg; as-fed basis) based on the apparent total tract digestion (ATTD) or standardized total tract digestion (STTD) of acid hydrolyzed ether extract (AEE) at 13 and 50 kg BW[1]

	Dietary treatment[2]															
Item	AV	CANO	CWGA	CWGB	COCO	CORA	CORB	FISH	FLAX	PALM	POUF	SOYA	SOYB	TAL	SEM	*P*-value
13 kg BW																
Apparent energy content																
DE[3]	8.37^{abc}	8.53^{a}	8.48^{ab}	8.46^{ab}	8.42^{abc}	8.28^{bc}	8.30^{bc}	8.56^{a}	8.29^{bc}	8.24^{c}	8.42^{abc}	8.41^{abc}	8.40^{abc}	8.25^{c}	0.08	0.041
ME[4]	8.20^{abc}	8.36^{a}	8.31^{ab}	8.29^{ab}	8.28^{abc}	8.12^{bc}	8.14^{bc}	8.38^{a}	8.13^{bc}	8.08^{c}	8.26^{abc}	8.24^{abc}	8.23^{abc}	8.08^{c}	0.07	0.041
NE[5]	7.22^{abc}	7.36^{a}	7.31^{ab}	7.29^{ab}	7.26^{abc}	7.14^{bc}	7.16^{bc}	7.38^{a}	7.15^{bc}	7.11^{c}	7.26^{abc}	7.25^{abc}	7.24^{abc}	7.11^{c}	0.06	0.041
Corrected energy content																
DE[6]	8.76^{abcd}	8.94^{ab}	8.93^{ab}	8.88^{abc}	8.85^{abcd}	8.73^{bcd}	8.74^{bcd}	8.97^{a}	8.72^{cd}	8.66^{d}	8.85^{abcd}	8.83^{abcd}	8.80^{abcd}	8.66^{d}	0.08	0.045
ME[4]	8.59^{abcd}	8.76^{ab}	8.75^{ab}	8.70^{abc}	8.68^{abcd}	8.56^{bcd}	8.56^{bcd}	8.79^{a}	8.54^{cd}	8.49^{d}	8.67^{abcd}	8.66^{abcd}	8.62^{abcd}	8.48^{d}	0.07	0.045
NE[5]	7.56^{abcd}	7.71^{ab}	7.70^{ab}	7.66^{abc}	7.64^{abcd}	7.53^{bcd}	7.54^{bcd}	7.73^{a}	7.51^{cd}	7.47^{d}	7.63^{abcd}	7.62^{abcd}	7.59^{abcd}	7.47^{d}	0.06	0.045
50 kg BW																
Apparent energy content																
DE[3]	8.42^{c}	8.69^{a}	8.54^{abc}	8.62^{ab}	8.50^{bc}	8.23^{d}	8.46^{bc}	8.56^{abc}	8.60^{ab}	8.40^{c}	8.50^{bc}	8.62^{ab}	8.50^{bc}	8.40^{c}	0.09	<0.001
ME[4]	8.25^{c}	8.52^{a}	8.37^{abc}	8.45^{ab}	8.33^{bc}	8.07^{d}	8.29^{bc}	8.39^{abc}	8.43^{ab}	8.24^{c}	8.33^{bc}	8.45^{ab}	8.33^{bc}	8.23^{c}	0.09	<0.001
NE[5]	7.26^{c}	7.50^{a}	7.36^{abc}	7.43^{ab}	7.33^{bc}	7.10^{d}	7.30^{bc}	7.38^{abc}	7.42^{ab}	7.25^{c}	7.33^{bc}	7.43^{ab}	7.33^{bc}	7.25^{c}	0.08	<0.001
Corrected energy content																
DE[6]	9.00^{def}	9.26^{a}	9.13^{abcde}	9.23^{ab}	9.12^{abcde}	8.87^{f}	9.08^{bcde}	9.16^{abcd}	9.18^{abc}	9.01^{cdef}	9.10^{abcde}	9.19^{abc}	9.07^{bcde}	9.00^{ef}	0.09	<0.001
ME[4]	8.82^{def}	9.08^{a}	8.94^{abcde}	9.04^{ab}	8.94^{abcde}	8.69^{f}	8.90^{bcde}	8.98^{abcd}	9.00^{abc}	8.83^{cdef}	8.91^{abcde}	9.00^{abc}	8.89^{bcde}	8.82^{ef}	0.09	<0.001
NE[5]	7.77^{def}	7.99^{a}	7.87^{abcde}	7.96^{ab}	7.86^{abcde}	7.65^{f}	7.83^{bcde}	7.90^{abcd}	7.92^{abc}	7.77^{cdef}	7.84^{abcde}	7.92^{abc}	7.82^{bcde}	7.76^{ef}	0.08	<0.001

[1]Determined via 120 pigs (8 pigs/treatment) with a d 7 BW of 12.3 ± 0.2 kg and a d 10 BW of 13.8 ± 0.4 kg and a d 53 BW of 49.1 ± 2.2 kg and a d 56 BW of 51.7 ± 1.7 kg.

[2]Each experimental diet included 95% of a corn-soybean meal basal diet and then 5% of either: corn starch (CNTR), animal-vegetable blend (AV), canola oil (CANO), choice white grease source A (CWGA), choice white grease source B (CWGB), coconut oil (COCO), corn oil source A (CORA), corn oil source B (CORB), fish oil (FISH), flaxseed oil (FLAX), palm oil (PALM), poultry fat (POUF), soybean oil source A (SOYA), soybean oil source B (SOYB), or tallow (TAL).

[3]Apparent $DE_{\text{dietary fat}}$ (Mcal/kg) = $GE_{\text{dietary fat}}$ (9.4 Mcal/kg; Atwater and Bryant, 1900; NRC, 2012) × ATTD of AEE (refer to percentages in Table 15).

[4]$ME_{\text{dietary fat}}$ (Mcal/kg) = DE × 98% (van Milgen et al., 2001; NRC, 2012).

[5]$NE_{\text{dietary fat}}$ (Mcal/kg) = ME × 88% (van Milgen et al., 2001; NRC, 2012).

[6]Corrected $DE_{\text{dietary fat}}$ (Mcal/kg) = $GE_{\text{dietary fat}}$ (9.4 Mcal/kg; Atwater and Bryant, 1900; NRC, 2012) × STTD of AEE (refer to percentages in Table 15).

Tables and Figures from Experiment #2

Table 18. Ingredient and nutrient composition (as-fed basis) of experimental diets d 0 to 35

Item	Control diet	Choice white grease diet	Corn oil diet
Ingredient %			
Corn[1]	63.30	56.63	56.61
Soybean meal	34.25	34.25	34.25
Dried distillers grains with solubles	-	-	-
Choice white grease	-	6.00	-
Corn oil	-	-	6.00
Limestone	0.89	0.99	0.99
L-lysine	0.09	0.24	0.25
DL-Methionine	0.06	0.14	0.15
L-Threonine	0.02	0.11	0.11
L-Tryptophan	0.02	0.04	0.04
Salt	0.43	0.43	0.43
Monocal	0.86	1.01	1.01
VTM finish	0.10	0.10	0.10
Enzyme blend	-	-	-
Blue synthetic dye	-	-	0.08
Red synthetic dye	-	0.08	-

[1]Titainum dioxide was added at 0.4% in place of corn to be used as indigestible marker from d 14 to 21.

Table 19. Blend of diets to create the 7 dietary treatments

Treatment	Dietary blend	Number of pens on dietary treatment
Control	100% Control diet (no blend)	17
2% Choice white grease	Blend (67% control diet + 33%, 6% choice white grease diet)	14
4% Choice white grease	Blend (33% control diet 1 + 67%, 6% choice white grease diet)	14
6% Choice white grease	100%, 6% Choice white grease diet (no blend)	14
2% Corn oil	Blend (67% control diet + 33%, 6% corn oil diet)	14
4% Corn oil	Blend (33% control diet + 67%, 6% corn oil diet)	14
6% Corn oil	100%, 6% Corn oil diet (no blend)	14

Table 20. Analyzed composition (as-fed basis) of the 7 treatment diets

	Dietary treatment						
		Choice white grease			Corn oil		
Item	Control	2%	4%	6%	2%	4%	6%
DM, %	91.33	91.51	91.69	91.86	91.47	91.62	91.77
GE, kcal/kg	3.87	3.99	4.20	4.24	3.97	4.08	4.18
Acid hydrolyzed ether extract, %	3.44	5.79	8.21	10.55	5.73	8.08	10.37

Table 21. Analyzed fatty acid concentration and composition of choice white grease and corn oil

Item	Choice white grease	Corn oil
Fatty acid, %		
Myristic acid (C14:0)	1.86	ND
Palmitic acid (C16:0)	27.40	12.34
Palmitoleic acid (C16:1)	2.37	0.12
Stearic acid (C18:0)	15.91	1.94
Oleic acid (C18:1)	34.66	27.35
Linoleic acid (C18:2)	15.81	55.05
Linolenic acid (C18:3)	0.77	1.37
Nonadecanoic acid (C19:0)	ND[2]	0.74
Arachidic acid (C20:0)	ND	0.38
Gadoleic acid (C20:1)	0.63	0.23
Eicosadienic acid (C20:2)	0.58	ND
Lignoceric acid (C24:0)	ND	0.14
Other	ND	0.35
Unsaturated to saturated fatty acid	1.21	5.68
Analyzed composition		
Free fatty acids, %	6.60	13.60
Moisture and volatile matter, %	0.98	0.52
Insoluble impurities, %	3.61	0.02
Unsaponifiable matter, %	0.57	1.80
Initial peroxide value, meq/kg	< 0.10	0.80

[1]Analysis via Barrow Agee Laboratories (Memphis, TN).
[2]Non-dectable.

Table 22. Growth performance and feed efficiency of pigs fed 2%, 4%, or 6% choice white grease or corn oil

	Dietary treatment								P-value		
		Choice white grease			Corn oil						
Item	Control	2%	4%	6%	2%	4%	6%	SEM	Treatment	Dietary fat level	Dietary fat source
Number of pens (*n* =)	17	14	14	14	14	14	14				
Initial weight (d 0), kg	28.6	28.6	28.6	28.5	28.6	28.6	28.6	0.6	0.99	0.99	0.99
Final weight (d 35), kg	61.8	61.7	61.1	62.4	62.5	62.0	61.9	0.9	0.96	0.77	0.62
d 0 to d 35											
ADG, kg	0.95	0.93	0.92	0.95	0.95	0.96	0.95	0.03	0.95	0.93	0.38
ADFI, kg	2.12	2.07	2.01	1.91	2.04	1.98	1.96	0.03	<0.001	0.001	0.85
Gain to feed	0.45	0.45	0.46	0.50	0.47	0.49	0.48	0.02	0.20	0.39	0.16

Table 23. Apparent total tract digestibility of dietary dry matter, gross energy, and acid hydrolyzed ether extract (as-fed basis)

	Dietary treatment								P-value		
		Choice white grease			Corn oil						
Item	Control	2%	4%	6%	2%	4%	6%	SEM	Treatment	Dietary fat level	Dietary fat source
Number of pens (*n* =)	17	14	14	14	14	14	14				
Initial weight (d 0), kg	28.6	28.6	28.6	28.5	28.6	28.6	28.6	0.6	0.99	0.99	0.99
Final weight (d 35), kg	61.8	61.7	61.1	62.4	62.5	62.0	61.9	0.9	0.96	0.77	0.62
Apparent total tract digestibility (d 19), %											
Dry matter	74.1	74.4	76.2	75.6	74.9	74.4	77.1	0.9	0.12	0.15	0.89
Gross energy	70.0	70.8	73.1	72.9	71.2	71.1	74.4	1.0	0.021	0.036	0.96
Acid hydrolyzed ether extract	-6.04	31.4	50.8	56.1	33.0	48.2	61.8	2.1	<0.001	<0.001	0.35
Dietary DE, Mcal/kg	2.71	2.83	3.01	3.09	2.83	2.90	3.11	0.04	<0.001	<0.001	0.38

Table 24. Comparison of predicted versus observed DE (Mcal/kg) values on d 19

Item	Observed DE	Powles et al. (1995) predicted DE[1]	Δ DE[2]	Kellner et al. (2017) predicted DE[3]	Δ DE
Source					
Choice white grease	8.08	8.16	0.08	7.71	-0.37
Corn oil	7.91	8.65	0.74	8.13	0.22
Predication error[4]	-	0.41	-	0.30	-
Prediction bias[5]	-	0.41	-	-0.08	-

[1]DE (kcal/kg) = [36.898 – (0.005 × free fatty acid, g/kg) – 7.330 × $^{e-0.906 \times \text{unsaturated fatty acid to SFA ratio}}$)]/0.004184 (Powles et al., 1995); refer to table 5.5 and 5.6 for dietary fatty acid and chemical composition.

[2]Delta DE (Mcal/kg) = predicted DE (Mcal/kg) – observed DE (Mcal/kg).

[3]DE (Mcal/kg) = 8.357 + [0.189 × unsaturated fatty acid:SFA] – [0.195 × FFA, %] – [6.768 × behenic acid, %] + [0.024 × PUFA, %].

[4]Prediction error = √ [(1/number of dietary fat treatments) × Σ (absolute differences between predicted and observed energy values)^2] (Lane et al., 2014).

[5]Prediciton bias = [(1/number of dietary fat treatments) × Σ (difference between predicted and observed energy values)] (smaller absolute value indicates greater accuracy of the equation; negative value indicates underestimation and positive value indicates overestimation; Lane et al., 2014).

Figure 1. Determination of the DE of choice white grease via linear regression analysis

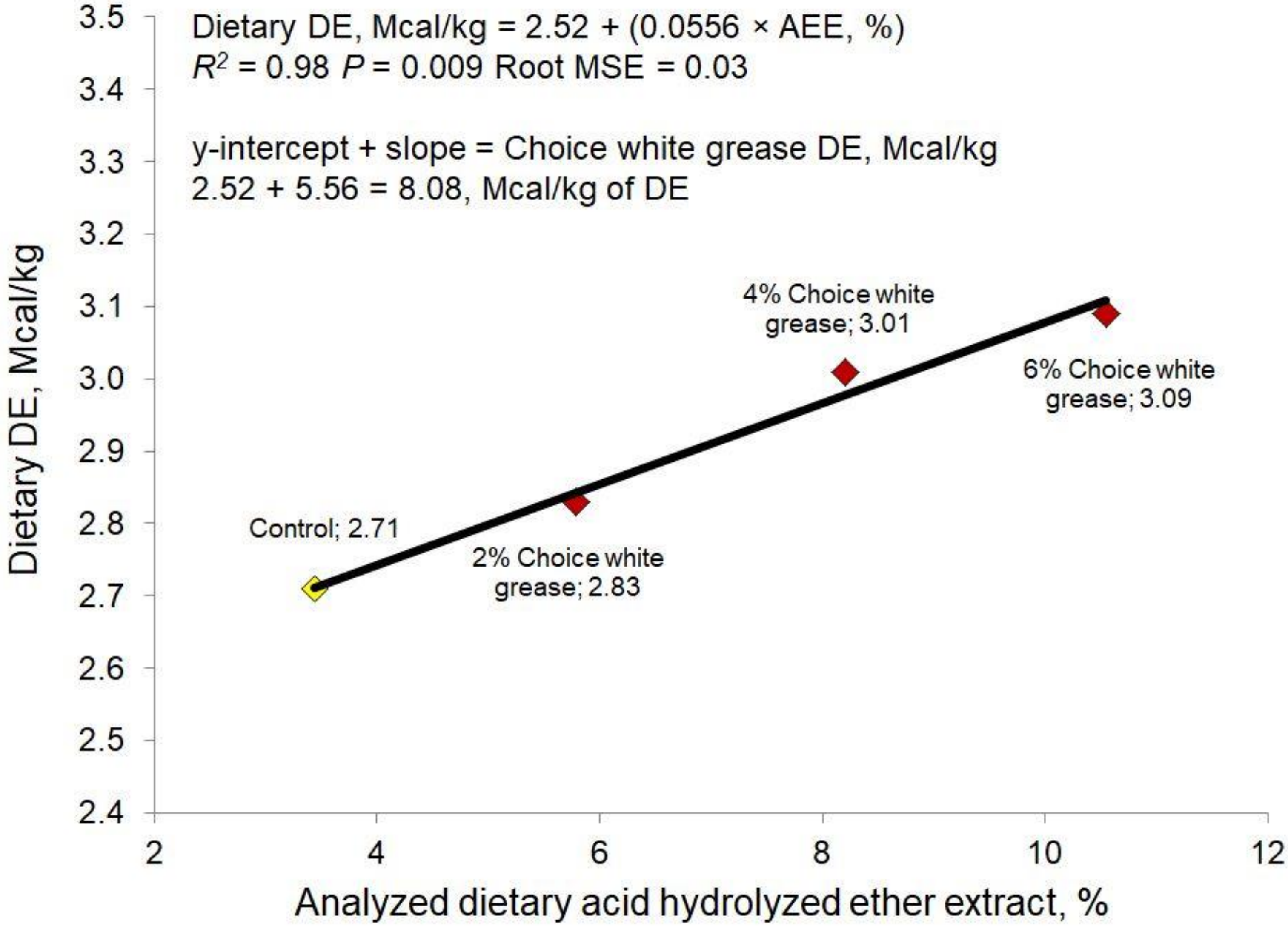

Figure 2. Determination of the DE of corn oil via linear regression analysis