Effects of dietary iodine value product on growth performance and carcass fat quality of finishing pigs[1]

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ABSTRACT: A total of 120 barrows (initial BW = 47.9 ± 3.6 kg; PIC 1050) were used in an 83-d study to determine the effects of dietary iodine value (IV) product (IVP) on growth performance and fat quality. Pigs were blocked by BW and randomly allotted to 1 of 6 treatments with 2 pigs per pen and 10 pens per treatment. Dietary treatments were fed in 3 phases and formulated to 3 IVP concentrations (low, medium, and high) in each phase. Treatments were 1) corn-soybean meal control diet with no added fat (low IVP), 2) corn-extruded expelled soybean meal (EESM) diet with no added fat (medium IVP), 3) corn-soybean meal diet with 15% distillers dried grains with solubles and choice white grease (DDGS + CWG; medium IVP), 4) corn-soybean meal diet with low CWG (medium IVP), 5) corn-EESM diet with 15% DDGS (high IVP), and 6) corn-soybean meal diet with high CWG (high IVP). On d 83, pigs were slaughtered and backfat and jowl fat samples were collected and analyzed. The calculated and analyzed dietary IVP values were highly correlated ($r^2 = 0.86$, $P < 0.01$). Pigs fed the control diet, EESM, or high CWG had greater ($P < 0.05$) ADG than pigs fed EESM + DDGS. Pigs fed the control diet had greater ($P < 0.05$) ADFI than pigs fed all other diets. Pigs fed EESM + DDGS and high CWG had improved ($P < 0.05$) G:F compared with pigs fed the control diet or DDGS + CWG. Pigs fed diets with DDGS had greater ($P < 0.05$) backfat and jowl fat IV, C18:2n-6, and PUFA and less SFA than pigs fed all other treatments. Pigs fed EESM had greater ($P < 0.05$) backfat and jowl fat IV, C18:2n-6, and PUFA than pigs fed the control diet, low CWG, or high CWG. Pigs fed low CWG or high CWG had greater ($P < 0.05$) jowl fat IV than control pigs. Feeding ingredients high in unsaturated fatty acids, such as DDGS and EESM, had a greater impact on fat IV than CWG, even when diet IVP was similar. Therefore, IVP was a poor predictor of carcass fat IV in pigs fed diets with different fat sources and amounts of unsaturated fats formulated with similar IVP. Dietary C18:2n-6 content was a better predictor of carcass fat IV than diet IVP.

Key words: dietary fat, distillers dried grains with solubles, extruded expelled soybeans, iodine value, iodine value product, pig

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INTRODUCTION

Alternative feed ingredients such as extruded expelled soybean meal (**EESM**) and dried distillers grains with solubles (**DDGS**) have been successfully included in swine diets (Webster et al., 2003; Stein and Shurson, 2009). However, both feedstuffs increase the amount of unsaturated fats in the diet and, therefore, may influence carcass fat quality because carcass fat composition is affected by dietary fatty acids (Brooks, 1971; Wood, 1984; Gatlin et al., 2002). Increasing the concentration of unsaturated fatty acids in pork carcass results in softer fat, which affects processing characteristics and the ability of pork products to meet export specifications (Carr et al., 2005).

Iodine value (**IV**) of a fat source is an estimate of the proportion of unsaturated fatty acids in that source of fat. Therefore, carcass fat IV is an indirect indicator of the percentage of unsaturated fatty acids, softness of fat, or rancidity (Hugo and Roodt, 2007). Acceptable IV of backfat ranges from 70 (Barton-Gade, 1987; Madsen et al., 1992; NPPC, 2000) to 75 g/100 g of fat (Boyd et al., 1997), but some US packing plants have set their maximum IV of jowl fat at 73 g/100 g (D. Petry, Triumph Foods LLC, St. Joseph, MO, personal communication). Using fat content of the diet

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and IV of the dietary fat source, Madsen et al. (1992) and Boyd et al. (1997) developed equations to predict backfat IV by calculating dietary IV product (**IVP**). However, data on the validity of these equations are limited. Likewise, the relationship between multiple diets with similar IVP but different sources and percentages of dietary fat has not been evaluated. Therefore, the objective of this study was to evaluate the effects of dietary IVP on finishing pig growth performance and carcass fatty acid composition.

MATERIALS AND METHODS

All experimental procedures used in this study were approved by the Kansas State University Institutional Animal Care and Use Committee.

Animals and Diets

One hundred twenty maternal line crossbred barrows (PIC 1050, Hendersonville, TN) with an average initial BW of 47.9 ± 3.6 kg were used in an 83-d experiment conducted at the Kansas State University Swine Teaching and Research Center finishing facility. Pigs were blocked by BW and allotted to 1 of 6 treatments with 10 replicate pens per treatment. Pigs were housed 2 per pen in 1.52 m × 1.52 m pens with totally slatted floors. Each pen was equipped with a 1-hole dry self-feeder and a nipple waterer to allow ad libitum access to feed and water. Diets were formulated by using NRC (1998) composition values for ingredients (Table 1), except an ME value of 3,420 kcal/kg was used for DDGS (Stein and Shurson, 2009). Pigs were fed a common corn-soybean meal-based diet for 7 wk before the start of the experiment. Dietary treatments were fed in 3 phases (d 0 to 26, d 26 to 55, and d 55 to 83) and formulated to have 3 concentrations of IVP (low, medium, or high) in each phase (Tables 1, 2, 3). Treatments were 1) corn-soybean meal control diet with no added fat (low IVP), 2) corn-EESM diet with no added fat (medium IVP), 3) corn-soybean meal diet with 15% DDGS and choice white grease (DDGS + CWG; medium IVP), 4) corn-soybean meal diet with low CWG (medium IVP), 5) corn-EESM diet with 15% DDGS (high IVP), and 6) corn-soybean meal diet with high CWG (high IVP). Diets were formulated to a constant concentration of standardized ileal digestible Lys per megacalorie of ME within each phase. Samples of DDGS and EESM used in the study were collected and analyzed in duplicate for DM (AOAC, 2006; 934.01), ether extract (920.39), CP (984.13), AA (982.3), and crude fiber (978.1; Table 4). The fatty acid profiles of DDGS, EESM, and CWG were also analyzed (AOAC, 2006; 996.06; Table 5). Dietary IVP was calculated as (IV of the dietary lipids × percentage dietary lipids) × 0.10 (Madsen et al., 1992) and calculated by using analyzed fatty acid profiles and IV of DDGS, EESM, and CWG. Fatty acid profiles of corn and soybean meal were derived from NRC (1998). The amount of dietary ingredients in each phase was altered to maintain a similar diet IVP for treatments 2, 3, and 4 (medium IVP) and for treatments 5 and 6 (high IVP). Calculated IVP in phases 1 to 3 were 34.4, 36.3, and 37.2 for the low levels; an average of 48.1, 52.3, and 46.3 for the medium levels; and an average of 56.2, 60.3, and 54.3 for the high levels, respectively. Pigs and feeders were weighed on d 12, 26, 41, 55, 69, and 83 to calculate ADG, ADFI, and G:F.

Fat Quality Analysis

At the end of the 83-d trial, all pigs were individually tattooed and shipped approximately 250 km to the Triumph Foods, LLC processing plant (St. Joseph, MO). Carbon dioxide stunning was used. Approximately 2 h after exiting deep chill, the right side jowl was removed with a perpendicular cut flush with the carcass shoulder. Approximately 100 g sample of backfat was removed from the 10th-rib area off the carcass midline. An attempt was made to remove all layers of backfat. The jowl fat and backfat samples were placed in a vacuum bag, vacuum sealed, stored at approximately 4°C, and then transported to Kansas State University under chilled conditions. Samples were frozen at −18°C until sample preparation and fatty acid analysis. Samples were thawed and dissected to separate adipose tissue from skin and lean tissue. Adipose tissue was subsampled and ground. Grinding was performed by cutting fat samples into approximately 1-cm^3 pieces, freezing them in a bath of liquid N_2, and grinding them into very fine particles in a stainless-steel grinding tub powered by a Waring commercial blender (Dynamics Corporation of America, New Hartford, CT). Ground fat (50 μg) was then weighed into screw-cap tubes with Teflon-lined caps. Fat (50 μg) was combined with 3 mL of methanolic-HCl and 2 mL of internal standard [2 mg/mL of methyl heptadecanoic acid (C17:0) in benzene] and subsequently heated in a water bath for 120 min at 70°C for transmethylation. Upon cooling, addition of 2 mL of benzene and 3 mL of K_2CO_3 were added which allowed the methyl esters to be extracted and transferred to a vial for subsequent quantification of the methylated fatty acids by GC for fatty acid analysis. Injection port and detector temperatures were 250°C with a flow rate of 1 mL of helium/min and a split ratio of 100:1. Oven temperature began at 140°C and increased at 2°C/min to 200°C then at 4°C/min to 245°C and held for 17 min.

From the fatty acid analysis, IV was calculated from the following equation (AOCS, 1998): IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723, where brackets indicate concentration (%).

Statistical Analysis

Data were analyzed as a randomized complete block design using the MIXED procedure (SAS Inst. Inc.,

Table 1. Phase 1 diet composition (as-fed basis)[1,2]

	Low dietary IVP	Medium dietary IVP			High dietary IVP	
Item	Control	EESM[3]	DDGS + CWG	Low CWG	EESM + DDGS	High CWG
Ingredient, %						
Corn	72.06	70.31	56.41	66.84	57.27	64.54
Soybean meal (46.5% CP)	25.09	—	24.44	27.06	—	27.86
DDGS	—	—	15.00	—	15.00	—
EESM	—	26.85	—	—	25.15	—
CWG[4]	—	—	1.55	3.25	—	4.70
Monocalcium phosphate (21% P)	1.10	1.15	0.75	1.15	0.75	1.20
Limestone	0.95	0.90	1.05	0.90	1.05	0.90
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[5]	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix[6]	0.15	0.15	0.15	0.15	0.15	0.15
L-Lys HCl	0.15	0.15	0.15	0.15	0.15	0.15
Calculated composition, %						
Total Lys	1.06	1.11	1.10	1.11	1.12	1.13
Standardized ileal digestible AA						
Lys	0.95	0.98	0.97	0.99	0.98	1.01
Met:Lys, %	28	28	31	27	31	27
Met+Cys:Lys, %	57	56	64	56	64	55
Thr:Lys, %	61	60	66	60	66	60
Trp:Lys, %	19	19	21	19	21	19
ME, kcal/kg	3,315	3,441	3,394	3,463	3,441	3,526
SID[7] Lys:ME, g/Mcal	2.58	2.58	2.58	2.58	2.58	2.58
Crude fat	3.2	4.5	5.4	6.3	5.1	7.6
Linoleic acid (18:2n-6)	1.53	2.39	2.08	1.87	2.72	2.02
CP (N × 6.25)	17.9	18.6	20.5	18.4	20.9	18.6
Ca	0.67	0.67	0.67	0.67	0.67	0.68
P	0.61	0.62	0.60	0.62	0.61	0.62
Available P	0.30	0.31	0.31	0.31	0.31	0.32
Calculated IVP,[8] g/100 g	34.4	53.8	50.6	52.4	60.1	60.4
Analyzed IVP[9]	33.3	50.0	57.4	46.3	53.8	54.7

[1]Diet fed in meal form from d 0 to 26. IVP = iodine value product.

[2]Diet composition was calculated using NRC (1998) values for ingredients, except 3,420 kcal/kg was used for the ME value of distillers dried grains with solubles (DDGS; Stein and Shurson, 2009).

[3]EESM = extruded expelled soybean meal.

[4]CWG = choice white grease.

[5]Provided (per kg of the diet): 6,615 IU of vitamin A, 826 IU of vitamin D_3, 26 IU of vitamin E, 2.65 mg of vitamin K (as menadione sodium bisulfate), 30 mg of niacin, 5 mg of riboflavin, 17 mg of pantothenic acid, and 0.02 mg of B_{12}.

[6]Provided (per kg of the diet): 40 mg of Mn (oxide), 165 mg of Fe (sulfate), 165 mg of Zn (oxide), 17 mg of Cu (sulfate), 0.30 mg of I (as Ca iodate), and 0.30 mg of Se (as Na selenite).

[7]SID = standardized ileal digestible.

[8]Iodine value of dietary lipids × % dietary lipids × 0.10.

[9]Iodine value of dietary lipids calculated from analyzed fatty acid composition × % analyzed dietary lipids × 0.10.

Cary, NC) with the pen as the experimental unit for all response criteria. The statistical model included block as a random effect and diet as the fixed effect. Least squares means were calculated for each independent variable and, if significant, separated with the PDIFF option of SAS. Correlation analysis was performed to determine the degree of association between calculated and analyzed dietary IVP. A simple regression was used to develop models for predicting carcass fat IV, using either the calculated IVP of the finisher phase 3 diets or the calculated dietary C18:2n-6 concentration as the independent variable. Statistical significance and tendencies were set at $P \leq 0.05$ and $P < 0.10$, respectively, for all statistical tests.

RESULTS

Chemical Analyses

Analyzed values for DM, CP, crude fiber, and crude fat in EESM and DDGS were similar to those used in diet formulation (Table 4). Likewise, the analyzed values for essential AA in EESM and DDGS were similar to those used in diet formulation, except that actual Lys in DDGS was greater (0.97 vs. 0.62%) than the calculated value. However, this value was within the range (0.64 to 1.04%) of Lys concentrations in DDGS obtained in previous experiments (Pedersen et al., 2007; Urriola et al., 2009).

Table 2. Phase 2 diet composition (as-fed basis)[1,2]

Item	Low dietary IVP	Medium dietary IVP		High dietary IVP	
	Control	EESM[3]	DDGS + CWG	Low CWG	EESM + DDGS	High CWG
Ingredient, %						
Corn	80.07	79.08	66.18	76.83	66.05	74.60
Soybean meal (46.5% CP)	17.28	—	15.87	18.33	—	19.05
DDGS	—	—	15.00	—	15.00	—
EESM	—	18.20	—	—	16.50	—
CWG[4]	—	—	0.50	2.15	—	3.65
Monocalcium phosphate (21% P)	1.00	1.05	0.65	1.05	0.65	1.05
Limestone	0.90	0.90	1.05	0.90	1.05	0.90
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[5]	0.13	0.13	0.13	0.13	0.13	0.13
Trace mineral premix[6]	0.13	0.13	0.13	0.13	0.13	0.13
L-Lys HCl	0.15	0.15	0.15	0.15	0.15	0.15
Calculated composition, %						
Total Lys	0.85	0.87	0.86	0.87	0.88	0.89
Standardized ileal digestible AA						
Lys	0.75	0.77	0.76	0.77	0.77	0.79
Met:Lys, %	30	30	35	30	35	29
Met+Cys:Lys, %	63	62	72	61	71	60
Thr:Lys, %	62	62	70	62	69	62
Trp:Lys, %	19	19	21	19	21	19
ME, kcal/kg	3,326	3,407	3,357	3,421	3,410	3,489
SID[7] Lys:ME, g/Mcal	2.14	2.14	2.14	2.14	2.14	2.14
Crude fat	3.4	4.3	4.6	5.4	4.9	6.8
Linoleic acid (18:2n-6)	1.64	2.22	2.08	1.87	2.55	2.02
CP (N × 6.25)	15.0	15.3	17.3	15.2	17.6	15.3
Ca	0.61	0.62	0.62	0.62	0.63	0.62
P	0.55	0.57	0.55	0.56	0.55	0.56
Available P	0.27	0.28	0.28	0.28	0.28	0.28
Calculated IVP,[8] g/100 g	36.3	49.4	46.6	48.2	55.8	56.5
Analyzed IVP[9]	37.7	46.7	49.8	44.0	58.9	54.5

[1]Diet fed in meal form from d 26 to 55. IVP = iodine value product.

[2]Diet composition was calculated using NRC (1998) composition values for ingredients except for the ME value of distillers dried grains with solubles (DDGS) in which 3,420 kcal/kg was used (Stein and Shurson, 2009).

[3]EESM = extruded expelled soybean meal.

[4]CWG = choice white grease.

[5]Provided (per kg of the diet): 5,513 IU of vitamin A, 689 IU of vitamin D_3, 22 IU of vitamin E, 2.2 mg of vitamin K (as menadione sodium bisulfate), 25 mg of niacin, 4.1 mg of riboflavin, 14 mg of pantothenic acid, and 0.02 mg of B_{12}.

[6]Provided (per kg of the diet): 33 mg of Mn (oxide), 138 mg of Fe (sulfate), 138 mg of Zn (oxide), 14 mg of Cu (sulfate), 0.25 mg of I (as Ca iodate), and 0.25 mg of Se (as Na selenite).

[7]SID = standardized ileal digestible.

[8]Iodine value of dietary lipids × % dietary lipids × 0.10.

[9]Iodine value of dietary lipids calculated from analyzed fatty acid composition × % analyzed dietary lipids × 0.10.

The most abundant fatty acid in both EESM and DDGS was C18:2n-6, which composed more than 50% of the total fatty acids (Table 5). The total PUFA content of EESM and DDGS was 62.4 and 54.8%, respectively. There were 4.2 and 3.14 times more PUFA than SFA in EESM and DDGS, respectively. In contrast, CWG contained mainly C18:1 *cis*-9, C16:0, C18:0, and C18:2n-6. Total SFA and MUFA content of CWG was 43 and 41%, respectively. Calculated IV values for EESM and DDGS were 134 and 129 g/100 g, respectively, which are about double the IV of CWG (62 g/100 g).

Analyzed dietary IVP was generally less than calculated values (Tables 1, 2, and 3). Averaging the 3 phases, the calculated and analyzed IVP of the diets were 36.0 and 36.0 for the low; 48.9 and 47.5 for the medium; and 56.9 and 54.0 for the high concentrations, respectively.

Growth Performance

Overall (d 0 to 83), pigs fed the control diet, EESM, or high CWG had greater ($P < 0.05$) ADG than pigs fed EESM + 15% DDGS, whereas the ADG of pigs fed DDGS + CWG and low CWG were not different from ADG of pigs fed any other treatment diets (Table 6). Pigs fed the control diet had greater ($P < 0.05$) ADFI than pigs fed all other treatments. Pigs fed EESM and DDGS + CWG had greater ($P < 0.05$) ADFI than pigs fed EESM + 15% DDGS. Pigs fed either low or high CWG had an ADFI that was not different ($P >$

Table 3. Phase 3 diet composition (as-fed basis)[1,2]

	Low dietary IVP	Medium dietary IVP			High dietary IVP	
Item	Control	EESM[3]	DDGS + CWG	Low CWG	EESM + DDGS	High CWG
Ingredient, %						
Corn	84.18	83.54	71.13	81.79	70.50	79.66
Soybean meal (46.5% CP)	13.37	—	11.67	14.06	—	14.74
DDGS	—	—	15.00	—	15.00	—
EESM	—	14.00	—	—	12.30	—
CWG[4]	—	—	—	1.70	—	3.15
Monocalcium phosphate (21% P)	0.80	0.80	0.45	0.85	0.45	0.85
Limestone	0.90	0.90	1.00	0.85	1.00	0.85
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[5]	0.13	0.13	0.13	0.13	0.13	0.13
Trace mineral premix[6]	0.13	0.13	0.13	0.13	0.13	0.13
L-Lys HCl	0.15	0.15	0.15	0.15	0.15	0.15
Calculated composition, %						
Total Lys	0.74	0.76	0.75	0.76	0.77	0.77
Standardized ileal digestible AA						
Lys	0.65	0.66	0.65	0.67	0.66	0.68
Met:Lys, %	32	32	38	32	38	31
Met+Cys:Lys, %	67	66	78	65	77	64
Thr:Lys, %	64	63	72	63	72	63
Trp:Lys, %	19	18	21	19	21	19
ME, kcal/kg	3,335	3,399	3,344	3,412	3,401	3,476
SID[7] Lys:ME, g/Mcal	1.85	1.85	1.85	1.85	1.85	1.85
Crude fat	3.5	4.2	4.2	5.1	4.8	6.5
Linoleic acid (18:2n-6)	1.70	2.15	2.08	1.88	2.47	2.03
CP (N × 6.25)	13.5	13.8	15.8	13.6	16.0	13.8
Ca	0.56	0.56	0.55	0.55	0.56	0.55
P	0.50	0.50	0.49	0.50	0.49	0.50
Available P	0.22	0.22	0.23	0.23	0.23	0.23
Calculated IVP,[8] g/100 g	37.2	47.4	44.8	46.7	53.7	54.8
Analyzed IVP[9]	37.1	45.9	46.5	41.3	55.3	47.0

[1]Diet fed in meal form from d 55 to 83. IVP = iodine value product.

[2]Diet composition was calculated using NRC (1998) composition values for ingredients, except for the ME value of distillers dried grains with solubles (DDGS), in which 3,420 kcal/kg was used (Stein and Shurson, 2009).

[3]EESM = extruded expelled soybean meal.

[4]CWG = choice white grease.

[5]Provided (per kg of the diet): 5,513 IU of vitamin A, 689 IU of vitamin D_3, 22 IU of vitamin E, 2.2 mg of vitamin K (as menadione sodium bisulfate), 25 mg of niacin, 4.1 mg of riboflavin, 14 mg of pantothenic acid, and 0.02 mg of B_{12}.

[6]Provided (per kg of the diet): 33 mg of Mn (oxide), 138 mg of Fe (sulfate), 138 mg of Zn (oxide), 14 mg of Cu (sulfate), 0.25 mg of I (as Ca iodate), and 0.25 mg of Se (as Na selenite).

[7]SID = standardized ileal digestible.

[8]Iodine value of dietary lipids × % dietary lipids × 0.10.

[9]Iodine value of dietary lipids calculated from analyzed fatty acid composition × % analyzed dietary lipids × 0.10.

0.10) from that of pigs fed all other treatments. Pigs fed EESM + 15% DDGS and high CWG had improved ($P < 0.05$) G:F compared with pigs fed the control diet or DDGS + CWG, whereas G:F of pigs fed EESM and low CWG were not different from G:F of pigs fed any other treatment diets.

Carcass Fatty Acid Composition

For backfat, pigs fed the 2 diets containing 15% DDGS had greater ($P < 0.02$) concentrations of C18:2n-6 and PUFA and lesser ($P < 0.05$) concentrations of C18:1 *cis*-9 and SFA than pigs from all other treatments (Table 7). As a result, PUFA:SFA and UFA:SFA of backfat were greatest ($P < 0.05$) in pigs fed DDGS. Pigs fed EESM diets had greater ($P < 0.05$) concentrations of C18:2n-6 and PUFA and decreased concentrations of C18:1 *cis*-9 and SFA compared with pigs in the control, low CWG, or high CWG diets. Pigs fed EESM had a greater ($P < 0.05$) PUFA:SFA than pigs fed the control diets or the CWG diets. Pigs fed low or high CWG diets had C18:2n-6 and total PUFA concentrations in backfat that were not different ($P > 0.10$) from those of pigs fed the control diet; however, SFA concentration was less ($P < 0.05$) for pigs fed CWG diets than those fed the control diet. In contrast, pigs fed low or high CWG diets had greater ($P < 0.05$) MUFA concentration in backfat than pigs fed diets with EESM or DDGS. Pigs fed low or high CWG diets had a PUFA:SFA similar ($P > 0.10$) to that of pigs fed the control diet. Pigs fed the

Table 4. Analyzed chemical composition of extruded expelled soybean meal (EESM) and distillers dried grains with solubles (DDGS) and values used in diet formulation (as-fed basis)

	EESM		DDGS	
Item	Calculated[1]	Analyzed	Calculated[1]	Analyzed
Proximate analysis, %				
DM	89.0	90.3	93.0	91.6
CP (N × 6.25)	46.5	44.2	27.7	28.4
Crude fiber	3.9	6.9	7.3	5.0
Ether extract	6.5	7.1	8.4	7.1
Essential AA, %				
Cys	0.74	0.71	0.52	0.51
Ile	2.16	2.05	1.03	1.07
Leu	3.66	3.42	2.57	2.94
Lys	3.02	2.87	0.62	0.97
Met	0.67	0.62	0.50	0.48
Thr	1.85	1.69	0.94	0.96
Trp	0.65	0.63	0.25	0.20
Val	2.27	2.17	1.30	1.36

[1]Calculated values used in diet formulation.

Table 5. Analyzed fatty acid profile of dietary ingredients

Item	EESM[1]	DDGS[2]	CWG[3]
Myristic acid (C14:0), %	0.09	0.07	1.76
Palmitic acid (C16:0), %	10.17	14.25	24.43
Palmitoleic acid (C16:1), %	0.10	0.15	2.35
Margaric acid (C17:0), %	0.12	0.10	0.89
Stearic acid (C18:0), %	3.78	2.11	15.63
Oleic acid (C18:1 *cis*-9), %	21.01	26.46	34.80
Vaccenic acid (C18:1n-7), %	1.48	0.76	2.34
Linoleic acid (C18:2n-6), %	54.48	52.86	13.07
α-Linolenic acid (C18:3n-3), %	7.55	1.52	1.05
Arachidic acid (C20:0), %	0.31	0.45	0.23
Gadoleic acid (C20:1)	ND[4]	0.29	0.04
Eicosadienoic acid (C20:2), %	0.10	0.10	0.45
Arachidonic acid (C20:4n-6), %	0.05	0.05	0.21
Other fatty acids, %	0.75	0.83	2.76
Total SFA,[5] %	14.87	17.45	43.31
Total MUFA,[6] %	22.69	27.75	41.33
Total PUFA,[7] %	62.43	54.80	15.33
Total *trans* fatty acids,[8] %	0.16	0.23	1.86
UFA:SFA ratio[9]	5.72	4.73	1.31
PUFA:SFA ratio[10]	4.20	3.14	0.35
Iodine value,[11] g/100 g	134	120	62

[1]Extruded expelled soybean meal.

[2]Distillers dried grains with solubles.

[3]Choice white grease.

[4]ND = not detectable.

[5]Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]), where brackets indicate concentration.

[6]Total MUFA = ([C14:1] + [C16:1] + [C18:1 *cis*-9] + [C18:1n-7] + [C20:1] + [C24:1]), where brackets indicate concentration.

[7]Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]), where brackets indicate concentration.

[8]Total *trans* fatty acids = ([C18:1 *trans*] + [C18:2 *trans*] + [C18:3 *trans*]), where brackets indicate concentration.

[9]UFA:SFA = [total MUFA + total PUFA]/total SFA.

[10]PUFA:SFA = total PUFA/total SFA.

[11]Calculated as iodine value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723, where brackets indicate concentration (AOCS, 1998).

control diet had a greater ($P < 0.01$) SFA concentration in backfat compared with those fed all other diets.

For jowl fat, pigs fed diets with 15% DDGS or EESM had greater ($P < 0.05$) C18:2n-6, PUFA, and PUFA:SFA and less ($P < 0.05$) C18:1 *cis*-9 and SFA than pigs fed the control diet or CWG diets (Table 8). Pigs fed EESM + 15% DDGS had greater ($P < 0.05$) C18:2n-6, PUFA, and PUFA:SFA than pigs fed 15% DDGS + CWG. Pigs fed CWG diets had concentrations of C18:2n-6, C18:1 *cis*-9, MUFA, and PUFA in jowl fat that were not different from ($P > 0.10$) those pigs fed the control diet. However, SFA concentration was less ($P < 0.05$) in pigs fed CWG diets than in pigs fed the control diet. Pigs fed the control diet or CWG diets had a greater ($P < 0.05$) MUFA concentration than pigs fed diets with either EESM or DDGS. Pigs fed the control diet had a greater ($P < 0.01$) SFA concentration in jowl fat compared with those pigs fed all other diets.

Pigs fed diets with 15% DDGS had greater ($P < 0.05$) IV in backfat and jowl fat than those pigs fed all other diets. Pigs fed EESM + DDGS had greater ($P < 0.05$) IV than pigs fed DDGS + CWG. Pigs fed EESM also had greater ($P < 0.05$) IV than pigs fed the control diet or CWG diets, although the difference in jowl fat with pigs fed high CWG was only numerical ($P > 0.10$). Pigs fed CWG diets had greater ($P < 0.05$) jowl fat IV than pigs fed the control diet, but no ($P > 0.10$) differences were observed in backfat IV. Pigs fed the control diet had the least ($P < 0.01$) jowl fat IV of pigs fed all other diets. When the calculated IVP in diets fed in phase 3 were related to backfat and jowl fat IV, there was a poor relationship ($P > 0.10$; Figure 1). However, the calculated dietary C18:2n-6 concentration was a better predictor of backfat and jowl fat IV ($P < 0.05$; Figure 2), explaining 73.4 and 90.3% of the variability in observed backfat and jowl fat IV, respectively.

Table 6. Effects of dietary iodine value product (IVP) on growth performance of finishing pigs[1]

	Low dietary IVP	Medium dietary IVP			High dietary IVP		
Growth performance	Control	EESM[2]	DDGS[3] + CWG[4]	Low CWG	EESM + DDGS	High CWG	SE
ADG, kg	0.94[a]	0.94[a]	0.91[ab]	0.93[ab]	0.83[b]	0.99[a]	0.04
ADFI, kg	2.89[a]	2.71[b]	2.69[b]	2.61[bc]	2.52[c]	2.66[bc]	0.07
G:F	0.32[a]	0.34[ab]	0.33[a]	0.35[ab]	0.38[b]	0.36[b]	0.03

[a–c]Means within a row with different superscripts differ ($P \leq 0.05$).

[1]Total of 120 pigs (initial BW = 47.9 ± 3.6 kg) with 2 pigs per pen and 10 pens per treatment.

[2]EESM = extruded expelled soybean meal.

[3]DDGS = distillers dried grains with solubles.

[4]CWG = choice white grease.

DISCUSSION

Effects on Growth Performance

Extruded expelled soybean meal is an alternative high-protein, high-oil soybean meal source produced via mechanical extraction of oil from soybeans (Woodworth et al., 2001). This results in a product with greater fat content (~7 vs. <1% fat) than conventionally processed solvent-extracted soybean meal (Woodworth et al., 2001). Like the results herein, Webster et al. (2003) found improved G:F of pigs fed diets containing EESM compared with those fed a control diet.

Feeding EESM with 15% DDGS reduced ADG and ADFI but improved G:F compared with those pigs fed the control diet. Some studies show a reduction in ADG and ADFI when the inclusion of DDGS is greater than 20% of the diet (Hinson et al., 2007; Linneen et al.,

Table 7. Effects of dietary iodine value product (IVP) on fatty acid composition of 10th-rib backfat[1]

	Low dietary IVP	Medium dietary IVP			High dietary IVP		
Item	Control	EESM[2]	DDGS[3] + CWG[4]	Low CWG	EESM + DDGS	High CWG	SE
Myristic acid (C14:0), %	1.42[bc]	1.36[ab]	1.31[a]	1.46[c]	1.32[a]	1.41[bc]	0.03
Palmitic acid (C16:0), %	26.05[c]	25.14[b]	23.93[a]	25.47[bc]	23.86[a]	24.90[b]	0.27
Palmitoleic acid (C16:1), %	2.35[bc]	2.18[b]	2.09[ab]	2.53[c]	1.95[a]	2.25[b]	0.08
Margaric acid (C17:0), %	0.51[ab]	0.52[b]	0.51[ab]	0.54[b]	0.46[a]	0.50[ab]	0.02
Stearic acid (C18:0), %	14.20[c]	13.37[bc]	12.09[a]	12.97[ab]	12.20[a]	13.36[bc]	0.32
Oleic acid (C18:1 *cis*-9), %	39.12[c]	37.50[b]	37.36[ab]	39.79[cd]	36.34[a]	40.71[d]	0.42
Vaccenic acid (C18:1n-7), %	2.59[c]	2.41[b]	2.36[b]	2.81[d]	2.20[a]	2.81[d]	0.06
Linoleic acid (C18:2n-6), %	11.16[a]	14.44[b]	17.27[c]	11.75[a]	18.39[c]	11.32[a]	0.55
α-Linolenic acid (C18:3n-3), %	0.52[a]	0.92[c]	0.73[b]	0.59[a]	0.98[c]	0.57[a]	0.04
Arachidic acid (C20:0), %	0.30[b]	0.30[bc]	0.27[ab]	0.26[a]	0.27[ab]	0.25[a]	0.01
Eicosadienoic acid (C20:2), %	0.57[a]	0.68[b]	0.80[c]	0.60[a]	0.83[c]	0.66[b]	0.02
Arachidonic acid (C20:4n-6), %	0.19[ab]	0.18[a]	0.22[bc]	0.20[abc]	0.21[b]	0.19[ab]	0.01
Other fatty acids, %	1.01	1.00	1.11	1.02	1.03	1.06	0.03
Total SFA,[5] %	42.83[c]	41.06[b]	38.48[a]	41.03[b]	38.43[a]	40.78[b]	0.52
Total MUFA,[6] %	44.44[c]	42.43[b]	42.15[b]	45.50[cd]	40.83[a]	46.16[d]	0.47
Total PUFA,[7] %	12.74[a]	16.51[b]	19.37[c]	13.47[a]	20.74[c]	13.05[a]	0.65
Total *trans* fatty acids,[8] %	0.33[b]	0.28[a]	0.30[b]	0.33[b]	0.30[a]	0.37[c]	0.01
UFA:SFA ratio[9]	1.34[a]	1.44[b]	1.60[c]	1.44[b]	1.61[c]	1.45[b]	0.03
PUFA:SFA ratio[10]	0.30[a]	0.40[b]	0.51[c]	0.33[a]	0.54[c]	0.32[a]	0.02
Iodine value,[11] g/100 g	59.92[a]	64.99[b]	69.34[c]	62.11[a]	70.78[c]	61.82[a]	0.94

[a–d]Means within a row with different superscripts differ ($P \leq 0.05$).

[1]Total of 120 pigs (initial BW = 47.9 ± 3.6 kg) with 2 pigs per pen and 10 pens per treatment.

[2]EESM = extruded expelled soybean meal.

[3]DDGS = distillers dried grains with solubles.

[4]CWG = choice white grease.

[5]Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]), where brackets indicate concentration.

[6]Total MUFA = ([C14:1] + [C16:1] + [C18:1 *cis*-9] + [C18:1n-7] + [C20:1] + [C24:1]), where brackets indicate concentration.

[7]Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]), where brackets indicate concentration.

[8]Total *trans* fatty acids = ([C18:1 *trans*] + [C18:2 *trans*] + [C18:3 *trans*]), where brackets indicate concentration.

[9]UFA:SFA = [total MUFA + total PUFA]/total SFA.

[10]PUFA:SFA = total PUFA/total SFA.

[11]Calculated as iodine value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723, where brackets indicate concentration (AOCS, 1998).

2008). However, a review by Stein and Shurson (2009) involving 25 growing-finishing experiments showed that feeding up to 20% corn DDGS maintained pig performance in most, but not all, experiments.

Adding CWG to diets reduced ADFI but did not affect ADG or G:F. This indicates that during this period, pigs were not in an energy-dependent phase of growth. The reduction in ADFI is a typical response when fat is added; however, most studies also show improvements in ADG and G:F (Pettigrew and Moser, 1991). The current study was conducted in a university research facility with 2 pigs per pen. De la Llata et al. (2001) observed greater improvements in growth rate to added dietary fat in a commercial finishing environment where feed intake is often up to 30% less than that of pigs housed in a university research environment.

Effects on Carcass Fatty Acid Composition

Linoleic acid (C18:2n-6) constitutes more than 50% (53 to 55%) of the fatty acids in both DDGS and EESM. Whittington et al. (1986) showed that C18:2n-6 and C18:1 *cis*-9 concentrations were inversely correlated in pork fat, which was also observed in the present study. Oleic acid (C18:1 *cis*-9) is the major component of pig adipose tissue, which constitutes more than 40% of total fat content (Hugo and Roodt, 2007). This suggests that addition of ingredients high in unsaturated fats, such as DDGS and EESM, changes the proportion of fatty acids in adipose tissues. Soft carcass fat is indicative of the high dietary C18:2 and PUFA concentrations, but this effect is mainly a result of a proportional decrease in SFA and changes in the distribution of fatty acids in fat tissues (Enser et al., 1984). Conversely, addition of CWG, which has greater concentrations of MUFA and SFA, did not affect C18:2n-6 and PUFA concentrations but reduced SFA in both backfat and jowl fat compared with the control.

Carcass fat IV provides an overall estimate of fatty acid unsaturation, which can serve as an indirect indicator of carcass fat firmness or rancidity (Hugo and Roodt, 2007). Acceptable backfat IV ranges from 70 (Barton-Gade, 1987; Madsen et al., 1992; NPPC, 2000) to 75 g/100 g of fat (Boyd et al., 1997), but some US packing plants have set their maximum jowl fat IV at 73 g/100 g (D. Petry, Triumph Foods LLC, St. Joseph,

Table 8. Effects of dietary iodine value product (IVP) on fatty acid composition of jowl fat[1]

	Low dietary IVP	Medium dietary IVP			High dietary IVP		
Item	Control	EESM[2]	DDGS[3] + CWG[4]	Low CWG	EESM + DDGS	High CWG	SE
Myristic acid (C14:0), %	1.48^{bc}	1.41^{ab}	1.42^{ab}	1.51^{c}	1.39^{a}	1.46^{bc}	0.03
Palmitic acid (C16:0), %	24.34^{d}	23.48^{bc}	23.05^{ab}	23.82^{cd}	22.59^{a}	23.18^{b}	0.20
Palmitoleic acid (C16:1), %	3.07^{b}	2.96^{ab}	2.90^{ab}	3.19^{b}	2.75^{a}	3.01^{ab}	0.11
Margaric acid (C17:0), %	0.46	0.49	0.49	0.51	0.46	0.53	0.02
Stearic acid (C18:0), %	10.57^{b}	10.05^{ab}	9.61^{a}	9.85^{a}	9.42^{a}	9.74^{a}	0.24
Oleic acid (C18:1 *cis*-9), %	42.89^{b}	41.32^{a}	41.33^{a}	43.15^{b}	40.82^{a}	43.71^{b}	0.40
Vaccenic acid (C18:1n-7), %	3.47^{bc}	3.30^{ab}	3.21^{a}	3.57^{c}	3.11^{a}	3.57^{c}	0.09
Linoleic acid (C18:2n-6), %	10.98^{a}	13.78^{b}	14.85^{b}	11.57^{a}	16.13^{c}	11.82^{a}	0.43
α-Linolenic acid (C18:3n-3), %	0.61^{a}	0.95^{d}	0.76^{c}	0.69^{bc}	0.97^{d}	0.69^{b}	0.28
Arachidic acid (C20:0), %	0.23^{a}	0.24^{a}	0.22^{ab}	0.21^{ab}	0.21^{ab}	0.20^{b}	0.01
Eicosadienoic acid (C20:2), %	0.61^{a}	0.73^{b}	0.79^{c}	0.66^{a}	0.84^{c}	0.72^{b}	0.02
Arachidonic acid (C20:4n-6), %	0.21^{a}	0.22^{ab}	0.23^{ab}	0.22^{ab}	0.23^{b}	0.23^{ab}	0.01
Other fatty acids, %	1.08	1.12	1.18	1.11	1.12	1.17	0.37
Total SFA,[5] %	37.43^{c}	36.07^{b}	35.18^{ab}	36.26^{b}	34.41^{a}	35.48^{b}	0.37
Total MUFA,[6] %	49.83^{b}	47.93^{a}	47.83^{a}	50.28^{b}	47.07^{a}	50.72^{b}	0.50
Total PUFA,[7] %	12.73^{a}	15.99^{b}	16.99^{b}	13.46^{a}	18.52^{c}	13.80^{a}	0.48
Total *trans* fatty acids,[8] %	0.34^{bc}	0.27^{a}	0.32^{b}	0.31^{b}	0.32^{bc}	0.36^{c}	0.01
UFA:SFA[9]	1.67^{a}	1.77^{bc}	1.85^{cd}	1.76^{b}	1.91^{d}	1.82^{bc}	0.03
PUFA:SFA[10]	0.34^{a}	0.44^{c}	0.48^{c}	0.37^{ab}	0.54^{d}	0.39^{b}	0.02
Iodine value,[11] g/100 g	64.60^{a}	68.80^{c}	70.16^{d}	66.25^{b}	72.30^{e}	67.09^{bc}	0.61

[a–d]Means within a row with different superscripts differ ($P \leq 0.05$).

[1]Total of 120 pigs (initial BW = 47.9 ± 3.6 kg) with 2 pigs per pen and 10 pens per treatment.

[2]EESM = extruded expelled soybean meal.

[3]DDGS = distillers dried grains with solubles.

[4]CWG = choice white grease.

[5]Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]), where brackets indicate concentration.

[6]Total MUFA = ([C14:1] + [C16:1] + [C18:1 *cis*-9] + [C18:1n-7] + [C20:1] + [C24:1]), where brackets indicate concentration.

[7]Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]), where brackets indicate concentration.

[8]Total *trans* fatty acids = ([C18:1 *trans*] + [C18:2 *trans*] + [C18:3 *trans*]), where brackets indicate concentration.

[9]UFA:SFA = [total MUFA + total PUFA]/total SFA.

[10]PUFA:SFA = total PUFA/total SFA.

[11]Calculated as iodine value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723, where brackets indicate concentration (AOCS, 1998).

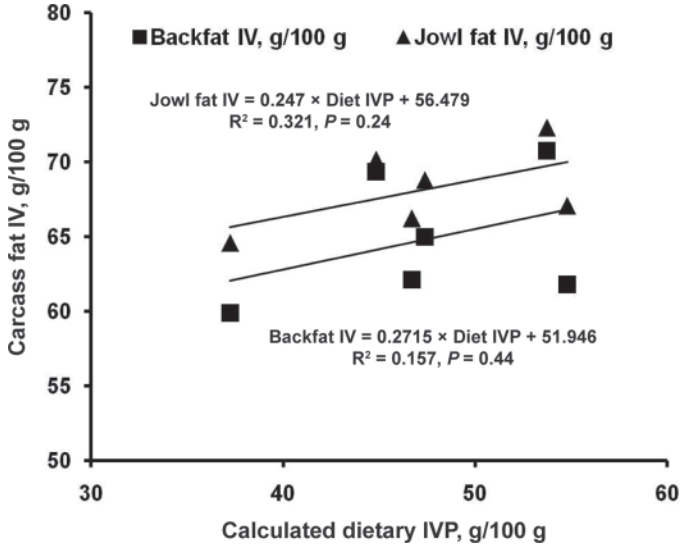

Figure 1. Regression analysis of calculated dietary iodine value (IV) product (IVP) on jowl fat and backfat IV.

MO, personal communication). The IV of backfat and jowl fat was less than 73 regardless of the dietary IVP. The fact that fed the DDGS containing diets had the greatest IV values of fat is in agreement with previous observations (Stender and Honeyman, 2008; Xu et al., 2010).

The amount of dietary crude fat appeared to be poorly related to carcass fat IV. For example, DDGS + CWG had a decreased fat content but greater proportion of PUFA than the high CWG diet. Because dietary PUFA are the most effective inhibitors of de novo fatty acid synthesis (Clarke et al., 1990; Bee et al., 1999, 2002), they may have a greater effect on carcass fat IV than the prediction equations indicated. This appeared to be the case in this study because pigs fed DDGS + CWG had considerably greater backfat and jowl IV than pigs fed high CWG.

Some US commercial packing plants collect jowl fat samples to monitor carcass fat IV because it is easy to collect and does not affect the value of other cuts, especially pork bellies. However, results of this study suggest that although the trend in IV changes of the 2 fat depots is similar, the magnitude of the response may be different. For example, both backfat and jowl fat IV increased in pigs fed DDGS compared with pigs fed the control diet; however, the average increase in jowl fat IV was only 65% (6.6 vs. 10.1% units) of the rate of change in backfat IV. Overall, the results suggest that jowl fat IV may be able to predict the general trend in IV changes in other fat depots (e.g., backfat); however, it does not accurately predict backfat IV.

Evans et al. (2009) observed that backfat and LM intramuscular fat were better indicators of belly IV than jowl fat. Differences in fatty acid composition between tissues could be partly explained by differences in fat tissue development (Brooks, 1971; Lizardo et al., 2002). For example, St. John et al. (1991) reported that fatty acid elongation is faster in bovine subcutaneous adipose tissue than in liver and observed desaturation only in adipose tissue. Xu et al. (2010) also suggested that different fat depots may have different lipogenic activities and that PUFA content of intramuscular fat and backfat of pigs as influenced by dietary fat may be different. This may be due to greater concentrations of structural lipids, such as phospholipids, in muscle than in backfat. Warnants et al. (1999) reported that structural lipids are not as readily affected by diet as depot lipids.

Analyzed IVP in each phase followed an increasing trend as intended. The greater degree of linear association between the calculated and analyzed dietary IVP values suggests that the IVP equation developed by Boyd et al. (1997) is valid in predicting actual diet IVP. It was expected that treatments formulated at similar IVP would have similar backfat IV; however, the results did not support this assumption. Even though the control diet was formulated to a low IVP, backfat IV of the control pigs was similar to that of pigs fed low CWG and high CWG, which were formulated to a medium and high IVP, respectively. For treatments formulated at a medium (EESM, DDGS + CWG, and low CWG) and high (EESM + DDGS and high CWG) IVP, each treatment within IVP resulted in significantly different backfat IV. Thus, IVP alone was not an accurate predictor of carcass fat IV when dietary fat differed in concentration and degree of unsaturation. However, the calculated dietary C18:2n-6 concentration was a better predictor of backfat and jowl fat IV. This may be due to the fact that C18:2n-6 in pork fat is the most abundant fatty acid and is mainly derived from dietary fat sources (Rosenvold and Andersen, 2003). Likewise, Wood et al. (2003) observed that C18:2n-6 showed the greatest correlation with fat firmness.

In conclusion, feeding ingredients with large amounts of unsaturated fat, such as EESM and DDGS, had a

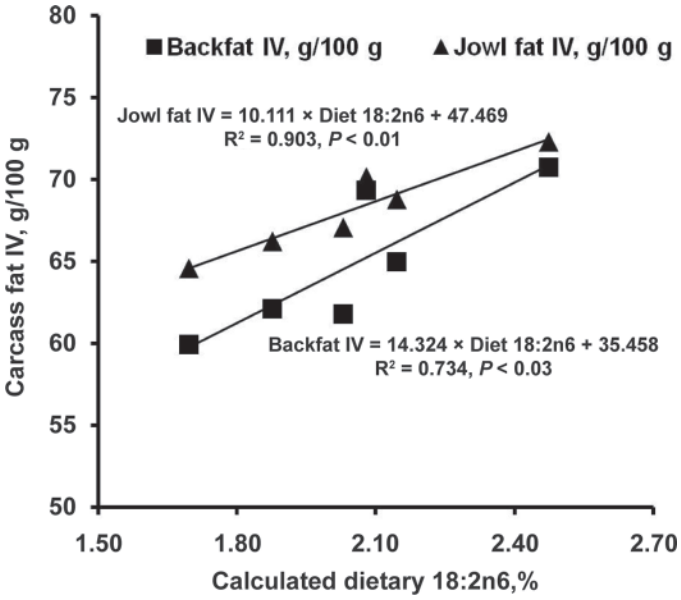

Figure 2. Regression analysis of calculated dietary linoleic acid (C18:2n-6) content on jowl fat and backfat iodine value (IV).

greater impact on fat IV than CWG, even when dietary IVP was similar. Therefore, IVP was a poor predictor of backfat IV when diets were formulated at similar IVP levels from different fat sources and with various degrees of fatty acid unsaturation. Dietary C18:2n-6 concentration was a better predictor of carcass fat IV than diet IVP. Jowl fat IV may be able to predict the general trend in IV changes; however, it overestimates backfat IV.

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