

# Pork fat quality of pigs fed distillers dried grains with solubles with variable oil content and evaluation of iodine value prediction equations<sup>1</sup>

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**ABSTRACT:** Back, belly, and jowl fat samples of pigs fed control corn-soybean meal-based diets and diets containing 4 sources of distillers dried grains with solubles (DDGS) were used to determine the impact of feeding DDGS with variable oil content on pork fat quality and to evaluate the precision and accuracy of published iodine value (IV) prediction equations. Dietary treatments consisted of 4 corn-soybean meal diets containing 40% DDGS from different sources with 10.7, 5.6, 14.2, or 16.0% ether extract (EE; as-fed) content. Diets did not contain any other supplemental lipid sources. Regardless of fat depot, SFA content (g/100 g fat) of pigs fed 5.6% EE DDGS (35.4) was greater ( $P < 0.05$ ) than that of pigs fed 14.2 or 16.0% EE DDGS sources (34.4 and 30.2, respectively) and tended to be greater ( $P < 0.10$ ) than that of pigs fed 10.7% EE DDGS (34.6). Pigs fed 10.7 and 14.2% EE DDGS had greater ( $P < 0.01$ ) SFA concentration than pigs fed 16.0% EE DDGS. Regardless of fat depot, MUFA content (g/100 g fat) of pigs fed 10.7, 5.6, and 14.2% DDGS sources were similar (43.7, 43.1, and 43.0, respectively) but were greater ( $P < 0.01$ ) than that

of pigs fed 16.0% EE DDGS (40.0). A dietary treatment  $\times$  fat depot interaction was observed for PUFA ( $P < 0.05$ ) and IV ( $P = 0.079$ ). Pigs fed 10.7, 5.6, and 14.2% DDGS sources had reduced ( $P < 0.01$ ) PUFA concentration and IV compared with pigs fed 16.0% EE DDGS, but the magnitude of responses in PUFA and IV to the variable oil content of DDGS was greater in backfat than in belly and jowl fat. Carcass fat IV data were used to evaluate prediction error (PE) and bias of published carcass fat IV prediction equations. Equations using dietary C18:2 content or IV product as a single predictor resulted in highly variable PE (g/100 g) ranging from 3.43 to 8.36 and bias (g/100 g) ranging from -5.05 to 5.66. Using equations that included additional diet composition information and pig growth performance factors decreased PE (3.27 to 4.73) and bias (-3.37 to 1.73) of prediction for backfat compared with equations only based on the characteristics of dietary lipid, but this improvement was limited in the prediction for belly and jowl fat. Predictions based on percentage of DDGS in diets had the greatest PE (6.66 to 9.19) and bias (5.53 to 8.00).

**Key words:** DDGS, iodine value, pork fat quality, prediction equations

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## INTRODUCTION

Corn distillers dried grains with solubles (**DDGS**) have been used widely in swine diets as a cost effective source of energy and AA. However, reduced pork fat firmness has been reported when  $> 20\%$  DDGS are add-

ed in growing-finishing diets (Xu et al., 2010; Graham et al., 2014), which is the result of a high concentration of unsaturated fatty acids (**FA**) in DDGS. Traditional DDGS sources have contained more than 10% crude fat (Stein and Shurson, 2009), but in recent years, most ethanol plants have been extracting corn oil and producing DDGS with greater variation in oil content (5 to 12%; Kerr et al., 2013). Decreased oil content alleviates the negative effects of DDGS on pork fat quality (Graham et al., 2014), but the magnitude of this improvement has not been compared among DDGS sources. In addition, the FA profile of carcass fat varies among anatomical

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sites because of different rates of development (Lizardo et al., 2002) and activities of lipogenic enzymes in adipose tissue (Mourot et al., 1995). Thus, the changes in FA composition in response to the reduction of oil in DDGS may also differ among carcass fat depots.

Iodine value (IV) is a measurement of unsaturated:saturated FA in lipid and is used as a quality standard for evaluating pork fat firmness. Packers have established maximum acceptance of carcass fat IV ranging from 70 to 75 g/100 g (Benz et al., 2011). As a result, accurate prediction of carcass fat IV is essential for optimizing the use of DDGS in growing-finishing diets while maintaining acceptable pork fat quality. Equations have been developed to predict IV of carcass fat depots based on the composition and amount of dietary lipids consumed and pig growth performance. However, precision and accuracy of these equations have not been evaluated. This study was conducted to determine the effects of feeding 7 sources of DDGS with variable oil content on FA composition of carcass fat and to evaluate selected IV equations for back, jowl, and belly fat.

## MATERIALS AND METHODS

All experimental procedures in this study were approved by the University of Minnesota Institutional Animal Care and Use Committee.

### *Animals and Diets*

Barrows ( $n = 432$ ) were blocked by initial BW ( $22.0 \pm 4.3$  kg) and were allotted to 12 blocks (4 pens/block and 9 pigs/pen). Within blocks, pens were allotted randomly to 1 of 4 dietary treatments (12 replicates/treatment). Dietary treatments consisted of 4 corn and soybean meal-based diets containing 40% DDGS from different sources that contained 10.7, 5.6, 14.2, or 16.0% ether extract (EE; Table 1 and 2). Experimental procedures for animal management and dietary treatment were described by Wu (2015). Diets containing 10.7, 5.6, 14.2, and 16.0% EE DDGS sources used in this study refer to the dietary treatments “LOW,” “ML,” “MH,” and “HIGH” (dietary NE concentrations varied from low to high), respectively, defined by Wu (2015).

### *Sample Collection*

Samples of backfat (BF), belly, and jowl fat were collected from 2 pigs/pen with final BW closest to the pen average at the end of the experiment. All fat samples were obtained from the left side of the carcasses. Backfat samples ( $n = 96$ ) were collected from the midline opposite the last rib and included all 3 fat layers. Belly fat samples ( $n = 96$ ) were collected from the mid-

line opposite the last rib on the teat side of the belly, and jowl fat samples ( $n = 96$ ) were obtained from the anterior tip of the jowl. Samples were packaged in Whirl-Pak sample bags (Nasco, Fort Atkinson, WI), stored in a cooler with dry ice, and delivered to the University of Minnesota Swine Nutrition Laboratory within 2 h of collection. All fat samples were frozen with dry ice during transportation to the University of Missouri Agricultural Experiment Station Chemical Laboratory (AESCL; Columbia, MO) for analysis of FA profile.

### *Chemical Analysis and Calculations*

Fatty acid profiles (Method 996.06; AOAC, 2006) were determined at AESCL for 4 DDGS samples (Table 3), 17 complete diets (Table 4), and 288 carcass fat samples. Iodine value was calculated using the following equation (AOCS, 1998):  $IV = [C16:1] \times 0.95 + [C18:1] \times 0.86 + [C18:2] \times 1.732 + [C18:3] \times 2.616 + [C20:1] \times 0.785 + [C22:1] \times 0.723$ , where brackets indicate concentration. The iodine value product (IVP) of the diets was calculated using the following equation:  $IVP = \text{dietary IV} \times \% \text{ dietary lipids} \times 0.10$  (Madsen et al., 1992).

### *Statistical Analysis*

Statistical analysis was conducted using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) with pen as the experimental unit. Fatty acid profile and the IV of carcass fat samples were analyzed in a split-plot design with diet as the whole plot and fat depot as the subplot. The dietary treatment  $\times$  depot interaction was also included in the final statistical analysis. Least squares means were separated using the PDIFF option when  $P < 0.05$ , and trends are reported when  $0.05 < P < 0.10$ .

### *Evaluation of Iodine Value Predictions*

Carcass fat IV data of pigs fed corn and soybean meal-based control diets along with IV data from pigs fed 3 different sources of DDGS with variable oil content (Wu, 2015) were combined with the current dataset to evaluate the precision and accuracy of 18 selected prediction equations. Pigs in the Wu (2015) study were fed a corn-soybean meal-based control diet or 3 diets containing 40% DDGS with low (5.9% EE), medium (9.9% EE), or high (14.2% EE) oil concentrations. This experiment was conducted in the same facility with the same genetic line of pigs and followed the same experimental procedures as that used in the present study.

The predicted IV of pigs fed each dietary treatment was calculated using 8 published equations (Eq. [1] to [8]; Table 5) for BF, 5 equations (Eq. [9] to [13]) for jowl fat, 3 equations (Eq. [14] to [16]) for belly fat, and

**Table 1.** Diet composition, phase 1 and 2 (as-fed basis)

Item	Phase 1 (22 to 50 kg BW)				Phase 2 (50 to 75 kg BW)			
	10.7% EE DDGS <sup>1</sup>	5.6% EE DDGS <sup>1</sup>	14.2% EE DDGS <sup>1</sup>	16.0% EE DDGS <sup>1</sup>	10.7% EE DDGS	5.6% EE DDGS	14.2% EE DDGS	16.0% EE DDGS
<b>Ingredients, %</b>								
Corn	36.42	36.41	36.40	36.41	44.10	44.10	44.09	44.10
Soybean meal	20.59	20.59	20.59	20.59	13.52	13.52	13.52	13.52
DDGS	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Limestone	1.62	1.60	1.55	1.62	1.40	1.45	1.30	1.39
Monocalcium P (21% P)	0.51	0.48	0.57	0.37	0.17	0.17	0.28	0.08
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
VTM premix <sup>2</sup>	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-Lys HCl	0.21	0.17	0.22	0.33	0.15	0.10	0.14	0.24
DL-Met	–	–	–	0.01	–	–	–	–
L-Thr	–	0.09	–	–	–	–	–	–
L-Trp	–	0.01	0.02	0.02	0.01	0.01	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
<b>Calculated composition</b>								
NE, kcal/kg	2,176	2,246	2,331	2,445	2,236	2,303	2,390	2,503
CP, %	23.01	23.98	23.43	23.63	20.14	21.04	20.54	20.72
Ca, %	0.79	0.80	0.77	0.76	0.62	0.67	0.60	0.60
Total P, %	0.59	0.61	0.57	0.59	0.49	0.52	0.48	0.50
STTD <sup>3</sup> P, %	0.36	0.37	0.35	0.35	0.28	0.30	0.28	0.28
Ca: STTD P	2.14	2.11	2.14	2.11	2.14	2.16	2.07	2.07
Total Lys, %	1.25	1.27	1.31	1.37	1.00	1.01	1.04	1.09
SID <sup>4</sup> AA, %								
Lys	1.04	1.07	1.11	1.16	0.81	0.84	0.87	0.90
Met	0.34	0.38	0.34	0.34	0.30	0.35	0.31	0.29
Thr	0.73	0.86	0.75	0.76	0.63	0.68	0.66	0.66
Trp	0.18	0.18	0.19	0.20	0.14	0.15	0.15	0.16
SID Lys/NE, g/kcal	4.78	4.76	4.76	4.74	3.62	3.65	3.64	3.60
<b>Analyzed composition</b>								
DM, %	87.38	87.59	87.67	87.96	87.06	86.94	87.35	87.56
CP, %	23.42	23.98	23.40	24.07	19.89	21.00	20.76	20.77
EE, %	4.76	2.84	5.84	6.26	5.04	3.04	5.93	6.73
Crude fiber, %	4.86	4.72	4.81	4.37	4.89	4.56	4.97	4.70
ADF, %	8.50	6.09	7.63	7.40	8.33	6.04	6.73	6.83
NDF, %	14.22	13.97	15.92	14.40	14.96	14.16	16.28	14.17
Ca, %	0.85	0.71	0.73	0.79	0.75	0.56	0.57	0.55
P, %	0.67	0.61	0.57	0.56	0.50	0.51	0.48	0.51
AA, %								
Lys	1.29	1.12	1.27	1.34	0.97	1.00	0.94	0.99
Met	0.42	0.38	0.37	0.40	0.36	0.39	0.34	0.31
Thr	0.94	0.93	0.94	0.89	0.80	0.79	0.75	0.76
Trp	0.24	0.27	0.26	0.26	0.21	0.21	0.22	0.23

<sup>1</sup>Diets containing 40% dried distillers grains with solubles (DDGS) from different sources with 10.7, 5.6, 14.2, or 16.0% ether extract (EE; as-fed) content.

<sup>2</sup>VTM premix = vitamin-trace mineral premix, which provided the following nutrients per kilogram of diet: 8,818 IU vitamin A, 1,654 IU vitamin D<sub>3</sub>, 33 IU vitamin E, 3.3 mg vitamin K, 5.5 mg riboflavin, 33.1 mg niacin, 22.0 mg pantothenic acid, 0.03 mg vitamin B<sub>12</sub>, 0.3 mg iodine as ethylenediamine dihydroiodide, 0.3 mg selenium as sodium selenite, 55.1 mg zinc as zinc oxide, 33.1 mg iron as ferrous sulfate, 5.5 mg manganese as manganous oxide, and 3.9 mg copper as copper sulfate.

<sup>3</sup>STTD = standardized total tract digestible.

<sup>4</sup>SID = standardized ileal digestible. Coefficients for AA digestibility were determined by equations from Almeida et al. (2013) for DDGS, and NRC (2012) recommended coefficients were used for corn and soybean meal.

**Table 2.** Diet composition, phase 3 and 4 (as-fed basis)

Item	Phase 3 (75 to 100 kg BW)				Phase 4 (100 to 115 kg BW)				Holding <sup>2</sup>
	10.7% EE DDGS <sup>1</sup>	5.6% EE DDGS <sup>1</sup>	14.2% EE DDGS <sup>1</sup>	16.0% EE DDGS <sup>1</sup>	10.7% EE DDGS	5.6% EE DDGS	14.2% EE DDGS	16.0% EE DDGS	
<b>Ingredients, %</b>									
Corn	47.77	47.76	47.77	47.76	49.57	49.58	49.58	49.58	80.75
Soybean meal	10.01	10.01	10.01	10.01	8.25	8.25	8.25	8.25	16.72
DDGS	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	–
Limestone	1.34	1.39	1.29	1.38	1.34	1.38	1.27	1.38	0.96
Monocalcium P (21% P)	0.10	0.12	0.17	–	0.11	0.13	0.21	0.01	0.92
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
VTM premix <sup>3</sup>	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-Lys HCl	0.12	0.06	0.09	0.18	0.07	–	0.03	0.12	–
L-Trp	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01	–
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
<b>Calculated composition</b>									
NE, kcal/kg	2,262	2,328	2,415	2,528	2,272	2,339	2,426	2,538	2,403
CP, %	18.70	19.58	19.08	19.25	17.93	18.82	18.32	18.48	13.84
Ca, %	0.57	0.62	0.56	0.57	0.57	0.62	0.56	0.56	0.58
Total P, %	0.47	0.49	0.45	0.47	0.46	0.49	0.45	0.46	0.44
STTD <sup>4</sup> P, %	0.26	0.28	0.25	0.26	0.26	0.28	0.25	0.25	0.27
Ca: STTD P	2.16	2.18	2.20	2.16	2.16	2.18	2.20	2.20	2.15
Total Lys, %	0.87	0.88	0.90	0.94	0.77	0.78	0.80	0.84	0.73
SID <sup>5</sup> AA, %									
Lys	0.69	0.71	0.74	0.77	0.60	0.62	0.64	0.67	0.62
Met	0.29	0.33	0.29	0.28	0.28	0.32	0.28	0.27	0.21
Thr	0.58	0.63	0.61	0.61	0.56	0.60	0.58	0.58	0.44
Trp	0.12	0.13	0.13	0.14	0.11	0.11	0.12	0.12	0.14
SID Lys/NE, g/kcal	3.05	3.05	3.06	3.05	2.64	2.65	2.64	2.64	2.58
<b>Analyzed composition</b>									
DM, %	87.12	87.19	87.63	87.60	86.75	87.64	87.51	87.29	87.41
CP, %	18.70	19.23	19.00	19.03	17.06	19.15	18.72	18.03	12.13
EE, %	4.99	3.04	5.93	6.68	5.09	3.31	6.09	6.76	2.14
Crude fiber, %	5.04	4.53	4.58	4.39	4.71	4.37	4.49	4.37	4.63
ADF, %	8.26	5.56	7.20	7.19	8.28	5.89	7.03	6.53	3.40
NDF, %	16.43	14.19	16.55	15.02	16.21	13.97	16.29	14.08	9.17
Ca, %	0.64	0.80	0.63	0.52	0.77	0.66	0.58	0.64	0.56
P, %	0.46	0.49	0.47	0.48	0.45	0.60	0.41	0.50	0.37
AA, %									
Lys	0.81	0.85	0.82	0.96	0.74	0.78	0.79	0.87	0.72
Met	0.33	0.36	0.32	0.36	0.33	0.36	0.33	0.34	0.22
Thr	0.71	0.76	0.73	0.76	0.68	0.74	0.71	0.73	0.51
Trp	0.21	0.21	0.21	0.22	0.20	0.19	0.18	0.19	0.15

<sup>1</sup>Diets containing 40% dried distillers grains with solubles (DDGS) from different sources with 10.7, 5.6, 14.2, or 16.0% ether extract (EE; as-fed) content.

<sup>2</sup>Corn-soybean meal diet with no addition of DDGS that was fed to pigs 5 d before slaughter due to depletion of DDGS.

<sup>3</sup>VTM premix = vitamin-trace mineral premix, which provided the following nutrients per kilogram of diet: 8,818 IU vitamin A, 1,654 IU vitamin D<sub>3</sub>, 33 IU vitamin E, 3.3 mg vitamin K, 5.5 mg riboflavin, 33.1 mg niacin, 22.0 mg pantothenic acid, 0.03 mg vitamin B<sub>12</sub>, 0.3 mg iodine as ethylenediamine dihydroiodide, 0.3 mg selenium as sodium selenite, 55.1 mg zinc as zinc oxide, 33.1 mg iron as ferrous sulfate, 5.5 mg manganese as manganous oxide, and 3.9 mg copper as copper sulfate.

<sup>4</sup>STTD = standardized total tract digestible.

<sup>5</sup>SID = standardized ileal digestible. Coefficients for AA digestibility were determined by equations from Almeida et al. (2013) for DDGS, and NRC (2012) recommended coefficients were used for corn and soybean meal.

**Table 3.** Fatty acid analysis of distillers dried grains with solubles (DDGS) with variable ether extract (EE) content (as-fed basis)

Item	10.7%		5.6%		14.2%		16.0%	
	EE	DDGS	EE	DDGS	EE	DDGS	EE	DDGS
EE, %	10.70		5.61		14.19		15.98	
Fatty acids <sup>1</sup> , % of EE								
C14:0	0.13		0.10		0.07		0.10	
C16:0	15.70		15.59		15.34		14.63	
C16:1	0.20		0.23		0.13		0.14	
C17:0	0.07		0.07		0.08		0.08	
C18:0	2.19		2.58		2.15		2.05	
C18:1	24.27		25.75		24.61		25.62	
C18:2	53.53		51.76		53.92		53.87	
C18:3	1.80		1.74		1.63		1.61	
C20:0	0.48		0.47		0.49		0.43	
C20:1	0.37		0.35		0.36		0.34	
C22:0	0.24		0.32		0.29		0.27	
C24:0	0.32		0.37		0.29		0.28	
SFA <sup>2</sup>	19.11		19.47		18.70		17.83	
MUFA <sup>3</sup>	24.84		26.33		25.10		26.10	
PUFA <sup>4</sup>	55.32		53.50		55.55		55.47	
IV <sup>5</sup> , g/100 g	119		117		119		120	
IVP <sup>6</sup>	127		66		169		192	

<sup>1</sup>Fatty acids: myristic (C14:0), palmitic (C16:0), palmitoleic (C16:1), margaric (C17:0), stearic (C18:0), oleic (C18:1), linoleic (C18:2), linolenic (C18:3), arachidic (C20:0), gadoleic (C20:1), behenic (C22:0), and lignoceric (C24:0).

<sup>2</sup>Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

<sup>3</sup>Total MUFA = ([C14:1] + [C16:1] + [C18:1-9c] + [C18:1-11c] + [C20:1] + [C24:1]); brackets indicate concentration.

<sup>4</sup>Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

<sup>5</sup>Calculated iodine value = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration (AOCS, 1998).

<sup>6</sup>Iodine value product = IV × % ether extract × 0.10 (Madsen et al., 1992).

2 equations (Eq. [17] and [18]) for the average of the 3 fat depots. Linoleic acid (C18:2) concentration and the IVP of each dietary treatment were calculated as the average among feeding phases and were weighted for total feed consumption within each phase. Estimates of IV from prediction equations were compared with the observed IV (least squares means; Fig. 4) determined by analyzed FA composition for each carcass fat depot of pigs fed in the 2 experiments. The standard error of prediction (prediction error [PE]) and prediction bias were calculated using the following equations:

$$PE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2}$$

and

$$Bias = \frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)$$

**Table 4.** Fatty acid analysis of diets (as-fed basis)

Item	10.7%		5.6%		14.2%		16.0%		Holding <sup>2</sup>
	EE	DDGS <sup>1</sup>	EE	DDGS <sup>1</sup>	EE	DDGS <sup>1</sup>	EE	DDGS <sup>1</sup>	
EE, %	4.94		2.99		5.91		6.58		2.14
Fatty acids <sup>3</sup> , % of EE									
C14:0	0.12		0.08		0.07		0.05		0.11
C16:0	15.19		15.05		14.80		14.43		14.58
C16:1	0.19		0.19		0.15		0.17		0.10
C17:0	0.11		0.10		0.08		0.08		0.10
C18:0	2.38		2.62		2.09		2.14		2.44
C18:1	24.49		25.19		24.48		25.26		22.94
C18:2	52.90		52.14		54.29		53.95		51.41
C18:3	2.25		2.38		2.21		2.06		3.11
C20:0	0.46		0.44		0.37		0.39		0.59
C20:1	0.35		0.37		0.32		0.29		0.42
C22:0	0.28		0.30		0.23		0.24		0.27
C24:0	0.34		0.34		0.23		0.25		0.35
SFA <sup>4</sup>	18.88		18.93		17.89		17.57		18.44
MUFA <sup>5</sup>	25.03		25.75		24.95		25.72		23.46
PUFA <sup>6</sup>	55.15		54.52		56.50		56.01		54.52
IV <sup>7</sup> , g/100 g	119		119		121		121		117
IVP <sup>8</sup>	59		35		72		80		25

<sup>1</sup>Diets containing 40% distillers dried grains with solubles (DDGS) from different sources with 10.7, 5.6, 14.2, or 16.0% ether extract (EE; as-fed) content. Values are presented as the average among 4 phases and are weighted for total feed consumption in each phase.

<sup>2</sup>Corn-soybean meal diet with no addition of DDGS that was fed to pigs 5 d before slaughter due to depletion of DDGS.

<sup>3</sup>Fatty acids: myristic (C14:0), palmitic (C16:0), palmitoleic (C16:1), margaric (C17:0), stearic (C18:0), oleic (C18:1), linoleic (C18:2), linolenic (C18:3), arachidic (C20:0), gadoleic (C20:1), behenic (C22:0), and lignoceric (C24:0).

<sup>4</sup>Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

<sup>5</sup>Total MUFA = ([C14:1] + [C16:1] + [C18:1-9c] + [C18:1-11c] + [C20:1] + [C24:1]); brackets indicate concentration.

<sup>6</sup>Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

<sup>7</sup>Calculated iodine value = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration (AOCS, 1998).

<sup>8</sup>Iodine value product = IV × % ether extract × 0.10 (Madsen et al., 1992).

where  $y_i$  is the predicted carcass fat IV for the  $i$ th dietary treatment,  $\hat{y}_i$  is the observed carcass fat IV for the  $i$ th dietary treatment, and  $n$  is the total number of dietary treatments ( $n = 8$  for each fat depot; Lane et al., 2014).

## RESULTS AND DISCUSSION

### Pork Fat Quality

No dietary treatment × depot interactions were observed for the majority of the FA (except C18:2, C18:3, and PUFA) and, therefore, only the main effects of dietary treatment and anatomical site on the concentrations of these FA were presented in Tables 6 and 7, respectively. Regardless of fat depot, the SFA content of

**Table 5.** Selected prediction equations for iodine value (IV) of carcass backfat, jowl fat, belly fat, and the average of 3 fat depots

Item	Reference	Equation	R <sup>2</sup>
<b>Backfat</b>			
Eq. [1]	Madsen et al., 1992	$47.1 + 0.14 \times \text{IVP}^1 \text{ intake/d}$	0.86
Eq. [2]	Boyd et al., 1997	$52.4 + 0.315 \times \text{Diet IVP}$	–
Eq. [3]	Benz et al., 2011	$51.946 + 0.2715 \times \text{Diet IVP}$	0.16
Eq. [4]	Benz et al., 2011	$35.458 + 14.324 \times \text{Diet C18:2, \%}$	0.73
Eq. [5]	Cromwell et al., 2011	$64.5 + 0.432 \times \text{DDGS in diet, \%}$	0.92
Eq. [6]	Estrada Restrepo, 2013	$60.13 + 0.27 \times \text{Diet IVP}$	0.81
Eq. [7]	Estrada Restrepo, 2013	$70.06 + 0.29 \times \text{DDGS in diet, \%}$	0.81
Eq. [8]	Paulk et al., 2015 <sup>2</sup>	$84.83 + (6.87 \times \text{I EFA}) - (3.90 \times \text{F EFA}) - (0.12 \times \text{I d}) - (1.30 \times \text{F d}) - (0.11 \times \text{I EFA} \times \text{F d}) + (0.048 \times \text{F EFA} \times \text{I d}) + (0.12 \times \text{F EFA} \times \text{F d}) - (0.0060 \times \text{F NE}) + (0.0005 \times \text{F NE} \times \text{F d}) - (0.26 \times \text{BF})$	0.95
<b>Jowl fat</b>			
Eq. [9]	Benz et al., 2011	$56.479 + 0.247 \times \text{Diet IVP}$	0.32
Eq. [10]	Benz et al., 2011	$47.469 + 10.111 \times \text{Diet C18:2, \%}$	0.90
Eq. [11]	Estrada Restrepo, 2013	$64.54 + 0.27 \times \text{Diet IVP}$	0.81
Eq. [12]	Estrada Restrepo, 2013	$72.99 + 0.24 \times \text{DDGS in diet, \%}$	0.81
Eq. [13]	Paulk et al., 2015 <sup>2</sup>	$85.50 + (1.08 \times \text{I EFA}) + (0.87 \times \text{F EFA}) - (0.014 \times \text{I d}) - (0.050 \times \text{F d}) + (0.038 \times \text{I EFA} \times \text{I d}) + (0.054 \times \text{F EFA} \times \text{F d}) - (0.0066 \times \text{I NE}) + (0.071 \times \text{I BW}) - (2.19 \times \text{ADFI}) - (0.29 \times \text{BF})$	0.93
<b>Belly fat</b>			
Eq. [14]	Estrada Restrepo, 2013	$58.32 + 0.25 \times \text{Diet IVP}$	0.74
Eq. [15]	Estrada Restrepo, 2013	$67.35 + 0.26 \times \text{DDGS in diet, \%}$	0.75
Eq. [16]	Paulk et al., 2015 <sup>2</sup>	$106.16 + (6.21 \times \text{I EFA}) - (1.50 \times \text{F d}) - (0.11 \times \text{I EFA} \times \text{F d}) - (0.012 \times \text{I NE}) + (0.00069 \times \text{I NE} \times \text{F d}) - (0.18 \times \text{HCW}) - (0.25 \times \text{BF})$	0.94
<b>Average of 3 depots</b>			
Eq. [17]	Kellner, 2014	$58.102 + 0.2149 \times \text{Diet IVP}$	0.93
Eq. [18]	Kellner, 2014	$58.566 + 0.1393 \times \text{C18:2 intake/d, g}$	0.94

<sup>1</sup>Iodine value product = dietary IV × % dietary lipids × 0.10 (Madsen et al., 1992).

<sup>2</sup>I = initial diet, F = final diet, d = days of diet fed, EFA = essential fatty acids (C18:2 and C18:3; %), NE (kcal/kg), BW (kg), ADFI (kg), HCW (kg), and BF = backfat depth (mm).

**Table 6.** Effects of dietary distillers dried grains with solubles (DDGS) on the fatty acid profile of carcass fat samples (fatty acids with no significant dietary treatment × depot interaction)

Item <sup>1</sup>	10.7% EE DDGS <sup>2</sup>	5.6% EE DDGS <sup>2</sup>	14.2% EE DDGS <sup>2</sup>	16.0% EE DDGS <sup>2</sup>	SEM	P value
C14:0	1.30 <sup>ab</sup>	1.32 <sup>a</sup>	1.26 <sup>b</sup>	1.12 <sup>c</sup>	0.02	<0.01
C16:0	22.44 <sup>a</sup>	22.76 <sup>a</sup>	22.30 <sup>a</sup>	20.03 <sup>b</sup>	0.19	<0.01
C16:1	2.42 <sup>a</sup>	2.29 <sup>b</sup>	2.22 <sup>b</sup>	1.93 <sup>c</sup>	0.05	<0.01
C17:0	0.42 <sup>a</sup>	0.39 <sup>a</sup>	0.39 <sup>a</sup>	0.33 <sup>b</sup>	0.01	<0.01
C17:1	0.40 <sup>a</sup>	0.36 <sup>b</sup>	0.35 <sup>b</sup>	0.29 <sup>c</sup>	0.01	<0.01
C18:0	10.00 <sup>a</sup>	10.43 <sup>b</sup>	10.02 <sup>ab</sup>	8.23 <sup>c</sup>	0.16	<0.01
C18:1	39.73 <sup>a</sup>	39.26 <sup>a</sup>	39.16 <sup>a</sup>	36.61 <sup>b</sup>	0.28	<0.01
C20:0	0.24	0.25	0.24	0.23	0.01	0.19
C20:1	0.84 <sup>a</sup>	0.84 <sup>a</sup>	0.83 <sup>a</sup>	0.77 <sup>b</sup>	0.02	<0.01
C20:4	0.42 <sup>a</sup>	0.42 <sup>a</sup>	0.42 <sup>a</sup>	0.48 <sup>b</sup>	0.01	<0.01
SFA <sup>3</sup>	34.61 <sup>ab</sup>	35.38 <sup>a</sup>	34.41 <sup>b</sup>	30.17 <sup>c</sup>	0.32	<0.01
MUFA <sup>4</sup>	43.74 <sup>a</sup>	43.11 <sup>a</sup>	42.97 <sup>a</sup>	39.95 <sup>b</sup>	0.31	<0.01

<sup>a-c</sup>Means with different superscripts within a row differ ( $P < 0.05$ ).

<sup>1</sup>Concentrations of fatty acids are expressed as grams of fatty acid/100 g fat. Fatty acids: myristic (C14:0), palmitic (C16:0), palmitoleic (C16:1), margaric (C17:0), heptadecenoic (C17:1), stearic (C18:0), oleic (C18:1), linoleic (C18:2), linolenic (C18:3), arachidic (C20:0), gadoleic (C20:1), arachidonic (C20:4).

<sup>2</sup>Diets containing 40% DDGS from different sources with 10.7, 5.6, 14.2, or 16.0% ether extract (EE; as-fed) content.

<sup>3</sup>Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

<sup>4</sup>Total MUFA = ([C14:1] + [C16:1] + [C18:1-9c] + [C18:1-11c] + [C20:1] + [C24:1]); brackets indicate concentration.



**Table 7.** Effects of anatomical site (fat depot) on the fatty acid profile of carcass fat samples (fatty acids with no significant dietary treatment × depot interaction)

Item <sup>1</sup>	Back	Belly	Jowl	SEM	<i>P</i> value
C14:0	1.19 <sup>a</sup>	1.35 <sup>b</sup>	1.21 <sup>a</sup>	0.01	<0.01
C16:0	22.36 <sup>a</sup>	22.75 <sup>b</sup>	20.53 <sup>c</sup>	0.13	<0.01
C16:1	1.85 <sup>a</sup>	2.43 <sup>b</sup>	2.36 <sup>b</sup>	0.03	<0.01
C17:0	0.38 <sup>a</sup>	0.35 <sup>b</sup>	0.41 <sup>c</sup>	0.01	<0.01
C17:1	0.32 <sup>a</sup>	0.32 <sup>a</sup>	0.40 <sup>b</sup>	0.01	<0.01
C18:0	10.92 <sup>a</sup>	9.94 <sup>b</sup>	8.16 <sup>c</sup>	0.13	<0.01
C18:1	37.25 <sup>a</sup>	38.93 <sup>b</sup>	39.88 <sup>c</sup>	0.20	<0.01
C20:0	0.26 <sup>a</sup>	0.23 <sup>b</sup>	0.22 <sup>b</sup>	0.01	<0.01
C20:1	0.83 <sup>a</sup>	0.75 <sup>b</sup>	0.88 <sup>c</sup>	0.01	<0.01
C20:4	0.39 <sup>a</sup>	0.43 <sup>b</sup>	0.48 <sup>c</sup>	0.01	<0.01
SFA <sup>2</sup>	35.31 <sup>a</sup>	34.83 <sup>a</sup>	30.78 <sup>b</sup>	0.24	<0.01
MUFA <sup>3</sup>	40.59 <sup>a</sup>	42.82 <sup>b</sup>	43.92 <sup>c</sup>	0.23	<0.01

<sup>a-c</sup>Means with different superscripts within a row differ ( $P < 0.05$ ).

<sup>1</sup>Concentrations of fatty acids are expressed as grams of fatty acid/100 g fat. Fatty acids: myristic (C14:0), palmitic (C16:0), palmitoleic (C16:1), margaric (C17:0), heptadecenoic (C17:1), stearic (C18:0), oleic (C18:1), linoleic (C18:2), linolenic (C18:3), arachidic (C20:0), gadoleic (C20:1), arachidonic (C20:4).

<sup>2</sup>Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

<sup>3</sup>Total MUFA = ([C14:1] + [C16:1] + [C18:1-9c] + [C18:1-11c] + [C20:1] + [C24:1]); brackets indicate concentration.

pigs fed 5.6% EE DDGS was greater ( $P < 0.05$ ) than that of pigs fed 14.2 and 16.0% EE DDGS and tended ( $P < 0.10$ ) to be greater for pigs fed 10.7% EE DDGS. Furthermore, although the concentrations of SFA in pigs fed 10.7 and 14.2% EE DDGS were not different, they were greater ( $P < 0.01$ ) than those fed 16.0% EE DDGS. Among fat depots, BF and belly fat had similar SFA content but were greater ( $P < 0.01$ ) than that of jowl fat. Concentrations of MUFA in pigs fed 10.7, 5.6, and 14.2% EE DDGS sources were greater ( $P < 0.01$ ) than that of pigs fed 16.0% EE DDGS. Among fat depots, BF contained less ( $P < 0.01$ ) concentration of MUFA than belly and jowl fat, and the MUFA content of belly fat was lower ( $P < 0.01$ ) than that for jowl fat.

Significant dietary treatment × depot interactions ( $P < 0.05$ ) were observed for C18:2, C18:3, and PUFA content. In both belly and jowl fat, C18:2 content in pigs fed 10.7, 5.6, and 14.2% EE DDGS were lower ( $P < 0.01$ ) than those of pigs fed 16.0% EE DDGS (Fig. 1). In contrast for BF, pigs fed 16.0% EE DDGS had increased ( $P < 0.01$ ) C18:2 content compared with that of the other dietary treatments. Pigs fed 14.2% EE DDGS had greater ( $P < 0.01$ ) C18:2 in BF than pigs fed 5.6% EE DDGS but were not different from those fed 10.7% EE DDGS, and there was no difference among pigs fed 10.7 and 5.6% EE DDGS. Among fat depots, concentrations of C18:2 in BF and jowl fat were not different, but they were greater ( $P < 0.05$ ) than belly fat in pigs fed 10.7, 14.2, and 16.0% EE

**Table 8.** Feed, lipid, and linoleic acid intake of pigs fed dietary distillers dried grains with solubles (DDGS) with variable oil content

Item	10.7%	5.6%	14.2%	16.0%
	EE DDGS <sup>1</sup>	EE DDGS <sup>1</sup>	EE DDGS <sup>1</sup>	EE DDGS <sup>1</sup>
Overall ADFI, kg	2.53	2.63	2.45	2.41
Lipid intake, g/day	125.0	78.6	144.8	158.6
C18:2 intake, g/day	66.1	41.0	78.6	85.6

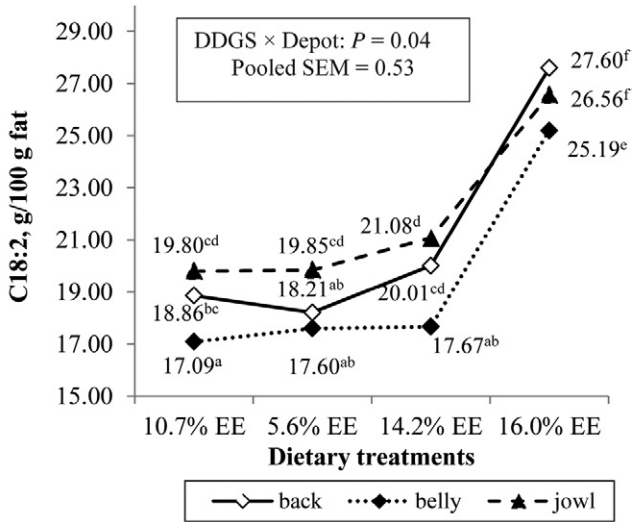
<sup>1</sup>Diets containing 40% DDGS from different sources with 10.7, 5.6, 14.2, or 16.0% ether extract (EE; as-fed) content.

DDGS. In pigs fed 5.6% EE DDGS, however, C18:2 contents in BF and belly fat were similar, but these contents were lower ( $P < 0.05$ ) than that of jowl fat.

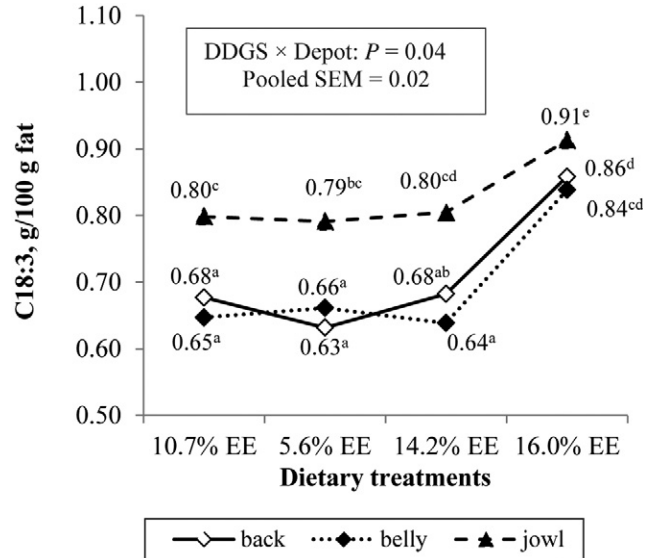
Pigs fed 5.6, 10.7, and 14.2% EE DDGS had decreased ( $P < 0.05$ ) C18:3 content compared with pigs fed 16% EE DDGS regardless of fat depot, but the magnitude of reduction was greater in BF and belly fat compared with that for jowl fat (dietary treatment × depot;  $P = 0.04$ ; Fig. 2). Among fat depots, BF and belly fat had lower ( $P < 0.05$ ) concentrations of C18:3 than jowl fat.

The amount of C18:2 represents about 95% of the total PUFA content (Fig. 3) in pork fat, and therefore, the results for PUFA content followed the same pattern as that for C18:2. A tendency ( $P = 0.079$ ) for a dietary treatment × depot interaction was observed for IV (Fig. 4). Dietary treatment groups shared the same mean separation patterns in each fat depot as that of C18:2 and PUFA. Among fat depots, jowl fat had a greater ( $P < 0.05$ ) IV than BF and belly fat regardless of dietary treatment. The IV of BF was greater ( $P < 0.05$ ) than that of belly fat in pigs fed 16.0% EE DDGS, but no difference was observed in pigs fed 10.7, 5.6, and 14.2% EE DDGS.

In general, pigs fed 10.7, 5.6, and 14.2% EE DDGS sources had greater concentrations of SFA and MUFA but had lower PUFA contents and IV compared with those of pigs fed 16.0% EE DDGS regardless of fat depot. These observations are explained mainly by the lower dietary lipid concentration of diets containing 10.7, 5.6, and 14.2% EE DDGS relative to diets containing 16.0% EE DDGS (Table 4). Graham et al. (2014) also reported an increased IV of carcass fat depots when pigs were fed DDGS sources with greater oil content compared with pigs fed reduced-oil DDGS sources. Elevated dietary lipid intake is effective in depressing de novo synthesis of FA, which are usually more saturated, and leads to greater tissue deposition of FA from dietary lipids (Farnworth and Kramer, 1987; Chilliard, 1993). In the current study, the dietary lipids were primarily from corn oil in DDGS or from corn, which are high in unsaturated FA and contain about 55% PUFA, 26% MUFA, and only 19% SFA (Table 3). Thus, reduced SFA de novo synthesis and increased unsaturated FA deposition resulted in a greater PUFA content and IV of carcass fat depots in pigs fed 16.0% EE DDGS than



**Figure 1.** Effects of dietary dried distillers grains with solubles (DDGS) with variable ether extract (EE) content on the linoleic acid (C18:2) concentration of backfat, belly, and jowl fat. Treatments include diets containing 40% DDGS from different sources with 10.7, 5.6, 14.2, or 16.0% EE content. <sup>a-f</sup>Means with different superscripts differ ( $P < 0.05$ ).

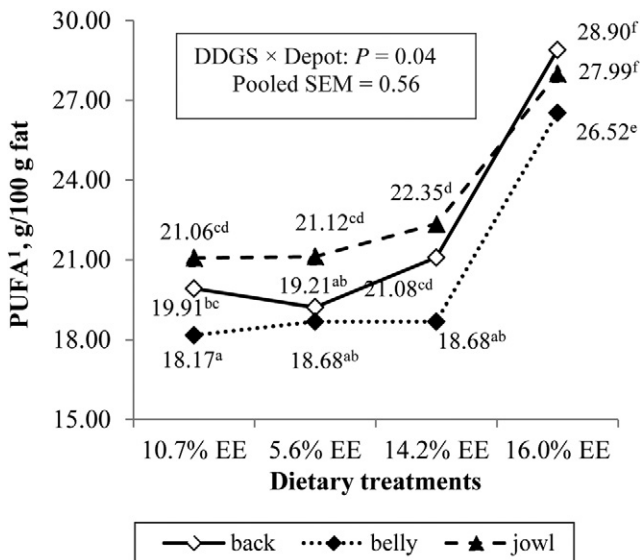


**Figure 2.** Effects of dietary dried distillers grains with solubles (DDGS) with variable ether extract (EE) content on the linolenic acid (C18:3) concentration of backfat, belly, and jowl fat. Treatments include diets containing 40% DDGS from different sources with 10.7, 5.6, 14.2, or 16.0% EE content. <sup>a-e</sup>Means with different superscripts differ ( $P < 0.05$ ).

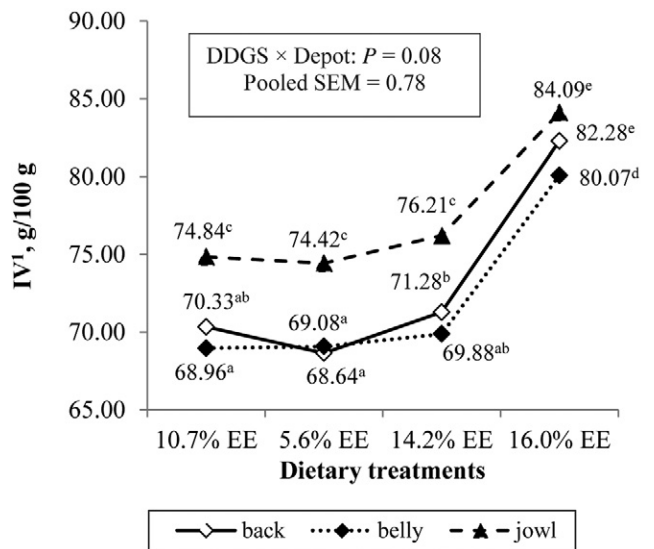
those in pigs fed the other dietary treatments. Therefore, it appears that the negative effect of feeding DDGS on pork fat quality may be reduced as more corn oil is extracted during DDGS production. However, although an EE content of 5.6% EE DDGS was 5.1 and 8.6% lower than the 10.7 and 14.2% EE DDGS sources, respectively, pigs fed these 3 DDGS sources generally had similar FA composition and IV in fat depots. It is possible that the oil content in 10.7 and 14.2% EE DDGS was less digestible and less utilized by pigs than that in other sources. Large variability in oil digestibility has been observed among

DDGS sources. In fact, Kerr et al. (2013) reported that the apparent total tract digestibility of EE varied from 52.7 to 81.2% among 15 sources of DDGS.

Significant dietary treatment × fat depot interactions observed for C18:2, C18:3, PUFA, and IV indicated that the magnitude of change in FA content, as a result of different amounts of dietary lipid intake, varied among the 3 fat depots. Based on the patterns shown in Fig. 1 to 4, it appears that BF seemed more responsive



**Figure 3.** Effects of dietary dried distillers grains with solubles (DDGS) with variable ether extract (EE) content on the PUFA concentration of backfat, belly, and jowl fat. Treatments include diets containing 40% DDGS from different sources with 10.7, 5.6, 14.2, or 16.0% EE content. <sup>1</sup>Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration. <sup>a-f</sup>Means with different superscripts differ ( $P < 0.05$ ).



**Figure 4.** Effects of dietary dried distillers grains with solubles (DDGS) with variable ether extract (EE) content on the iodine value (IV) of backfat, belly, and jowl fat. Treatments include diets containing 40% DDGS from different sources with 10.7, 5.6, 14.2, or 16.0% EE content. <sup>1</sup>Calculated iodine value = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration (AOCS, 1998). <sup>a-e</sup>Means with different superscripts differ ( $P < 0.05$ ).



**Table 9.** Comparison of prediction equations for backfat iodine value (IV; g/100 g)

Item	Present experiment				Wu (2015) <sup>1</sup>				PE <sup>3</sup>	Bias <sup>4</sup>
	10.7% EE DDGS <sup>2</sup>	5.6% EE DDGS <sup>2</sup>	14.2% EE DDGS <sup>2</sup>	16.0% EE DDGS <sup>2</sup>	CON	LOW	MED	HIGH		
Observed IV	70.33	68.64	71.28	82.28	57.72	74.11	74.35	78.96	–	–
Predicted IV <sup>5</sup>										
Eq. [1]	68.28	60.51	71.87	74.37	56.37	62.46	66.76	77.48	6.43	–4.95
Eq. [2]	70.92	63.55	74.97	77.46	60.07	65.43	69.33	78.71	4.60	–2.15
Eq. [3]	67.91	61.56	71.40	73.55	58.56	63.18	66.54	74.62	6.45	–5.05
Eq. [4]	72.88	57.75	81.40	86.27	51.01	61.56	69.68	88.49	8.36	–1.08
Eq. [5]	81.42	81.42	81.42	81.42	64.50	81.42	81.42	81.42	8.26	7.10
Eq. [6]	76.00	69.69	79.47	81.61	66.71	71.30	74.64	82.68	5.04	3.05
Eq. [7]	81.66	81.66	81.66	81.66	70.06	81.66	81.66	81.66	9.19	8.00
Eq. [8]	71.16	64.28	74.96	76.99	62.35	68.16	71.90	81.14	4.01	–0.84

<sup>1</sup>Previous experiment that was conducted in the same facility with the same genetic line of pigs and followed the same experimental procedures as the present experiment. CON = corn-soybean meal control diet, LOW = 40% low-oil (5.9%) distillers dried grains with solubles (DDGS) diet, MED = 40% medium-oil (9.9%) DDGS diet, and HIGH = 40% high-oil (14.2%) DDGS diet.

<sup>2</sup>Diets containing 40% DDGS from different sources with 10.7, 5.6, 14.2, or 16.0% ether extract (EE; as-fed) content.

<sup>3</sup>Prediction error (smaller value indicates greater precision of the equation).

<sup>4</sup>Prediction bias (smaller absolute value indicates greater accuracy of the equation; negative value indicates underestimation and positive value indicates overestimation).

<sup>5</sup>Prediction equations are presented in Table 5.

to lipid content differences among dietary treatments than belly and jowl fat. For example, pigs fed 5.6% EE DDGS had a reduced ( $P < 0.05$ ) C18:2 concentration in BF compared with that of pigs fed 14.2% EE DDGS, while there were no differences between these 2 dietary treatments in jowl or belly fat. Moreover, pigs fed 5.6% EE DDGS had a lower dietary C18:2 intake than pigs fed 16.0% EE DDGS (Table 8) and, consequently, had a reduced IV in 3 carcass fat depots. However, the magnitude of this reduction in IV was greater in BF (13.6 g/100 g) than in belly and jowl fat (11.0 and 9.7 g/100 g, respectively; Fig. 4). Some FA can be preferentially deposited in different tissues. A greater proportion of dietary C18:2 is deposited in BF compared with other carcass tissues (Kloareg et al., 2007). Therefore, the

C18:2 concentration of BF may be more sensitive to the changes in dietary C18:2 intake than belly and jowl fat. As the C18:2 content predominantly determines the PUFA content and the IV of carcass fat depots, the dietary treatment  $\times$  fat depot interactions observed for PUFA and IV can be mainly attributed to C18:2.

Researchers have reported a greater IV for jowl fat than for BF and belly fat (Evans et al., 2009; Duttlinger et al., 2012; Graham et al., 2014), which is consistent with the observation in the present study. Different rates of adipose tissue development can lead to variability in FA deposition among anatomical tissues (Lizardo et al., 2002). Late-developing tissues may deposit a greater amount of SFA than early-developing tissues because pigs have greater energy intake during the later stages of growth

**Table 10.** Comparison of prediction equations for jowl fat iodine value (IV; g/100 g)

Item	Present experiment				Wu (2015) <sup>1</sup>				PE <sup>3</sup>	Bias <sup>4</sup>
	10.7% EE DDGS <sup>2</sup>	5.6% EE DDGS <sup>2</sup>	14.2% EE DDGS <sup>2</sup>	16.0% EE DDGS <sup>2</sup>	CON	LOW	MED	HIGH		
Observed IV	74.84	74.42	76.21	84.09	62.20	71.22	72.25	76.89	–	–
Predicted IV <sup>5</sup>										
Eq. [9]	71.00	65.22	74.18	76.13	62.49	66.70	69.75	77.11	4.92	–3.69
Eq. [10]	73.89	63.20	79.90	83.34	58.44	65.89	71.63	84.91	5.57	–1.37
Eq. [11]	80.41	74.10	83.88	86.02	71.12	75.71	79.05	87.09	6.55	5.66
Eq. [12]	82.59	82.59	82.59	82.59	72.99	82.59	82.59	82.59	8.33	7.38
Eq. [13]	70.94	66.96	73.20	74.97	64.04	68.19	70.48	76.36	4.73	–3.37

<sup>1</sup>Previous experiment that was conducted in the same facility with the same genetic line of pigs and followed the same experimental procedures as the present experiment. CON = corn-soybean meal control diet, LOW = 40% low-oil (5.9%) distillers dried grains with solubles (DDGS) diet, MED = 40% medium-oil (9.9%) DDGS diet, and HIGH = 40% high-oil (14.2%) DDGS diet.

<sup>2</sup>Diets containing 40% DDGS from different sources with 10.7, 5.6, 14.2, or 16.0% ether extract (EE; as-fed) content.

<sup>3</sup>Prediction error.

<sup>4</sup>Prediction bias (smaller absolute value indicates greater accuracy of the equation; negative value indicates underestimation and positive value indicates overestimation).

<sup>5</sup>Prediction equations are presented in Table 5.

**Table 11.** Comparison of prediction equations for belly fat iodine value (IV; g/100 g)

Item	Present experiment				Wu (2015) <sup>1</sup>				PE <sup>3</sup>	Bias <sup>4</sup>
	10.7% EE DDGS <sup>2</sup>	5.6% EE DDGS <sup>2</sup>	14.2% EE DDGS <sup>2</sup>	16.0% EE DDGS <sup>2</sup>	CON	LOW	MED	HIGH		
Observed IV	68.96	69.08	69.88	80.07	60.17	70.74	72.03	76.41	–	–
Predicted IV <sup>5</sup>										
Eq. [14]	73.02	67.17	76.23	78.21	64.41	68.66	71.76	79.20	3.43	1.41
Eq. [15]	77.75	77.75	77.75	77.75	67.35	77.75	77.75	77.75	6.66	5.53
Eq. [16]	73.54	69.24	76.11	78.49	62.51	69.06	71.91	80.29	3.27	1.73

<sup>1</sup>Previous experiment that was conducted in the same facility with the same genetic line of pigs and followed the same experimental procedures as the present experiment. CON = corn-soybean meal control diet, LOW = 40% low-oil (5.9%) distillers dried grains with solubles (DDGS) diet, MED = 40% medium-oil (9.9%) DDGS diet, and HIGH = 40% high-oil (14.2%) DDGS diet.

<sup>2</sup>Diets containing 40% DDGS from different sources with 10.7, 5.6, 14.2, or 16.0% ether extract (EE; as-fed) content.

<sup>3</sup>Prediction error.

<sup>4</sup>Prediction bias (smaller absolute value indicates greater accuracy of the equation; negative value indicates underestimation and positive value indicates overestimation).

<sup>5</sup>Prediction equations are presented in Table 5.

and, consequently, have more excess energy to support de novo synthesis of FA. According to the fat accretion patterns (from the distal ends of the body toward the visceral cavity) of food animals characterized by Hammond (1932), pigs deposit lipids earlier in the jowl than in the loin and belly regions, which is in agreement with the greater IV observed in jowl fat. In addition, the lower rate of FA de novo synthesis in jowl fat is also attributed to its lower activities of lipogenic enzymes compared with BF and belly fat during the growing-finishing period (Mourot et al., 1995; Xu et al., 2010).

### Prediction of Iodine Value

The concentration of EE in the 7 sources of DDGS from the current study and that of Wu (2015) varied from 5.6 to 16.0%, which is similar to the range in oil content among sources of DDGS available in the current market. Consequently, the IVP of the 8 dietary treatments increased from 24.4 to 83.5 g/100 g, which resulted in a wide range of carcass fat IV (57.7 to 84.1 g/100 g) in the combined dataset used to evaluate the selected prediction equations. Prediction error is a measurement of precision and refers to the repeatability of an equation for different observations, whereas prediction bias is a measurement of accuracy and refers to the proximity of predicted estimates to the observed values. Among the equations to predict the IV of BF from diet composition, Eq. [8] resulted in the most accurate and precise IV estimates for BF because this equation demonstrated the lowest PE and bias (Table 9). For the prediction of jowl fat IV (Table 10), Eq. [9] and [13] provided similar estimates and had lower PE than the other equations for jowl fat, whereas Eq. [10] had the lowest prediction bias but a slightly greater PE than Eq. [9] and [13]. Among the equations for belly fat (Table 11), Eq. [14] and [16] had similar PE and bias, which were markedly

lower than those observed using Eq. [15]. Finally, the prediction from Eq. [17] resulted in more precise and accurate estimates for the average IV of the 3 fat depots compared with Eq. [18] (Table 12).

Fatty acid composition of pork fat is a reflection of the FA composition of dietary lipid composition and intake (Averette Gatlin et al., 2002; Benz et al., 2011). Therefore, the majority of the selected equations were developed based on the concentration and intake of dietary C18:2 (Eq. [4], [10], and [18]) or IVP (Eq. [1], [2], [3], [6], [9], [11], [14], and [17]), which is a composite value of the unsaturated:saturated FA ratio and the quantity of dietary lipids in swine diets. However, using dietary C18:2 or IVP as a single predictor variable resulted in highly variable PE ranging from 3.43 to 8.36 g/100 g and bias ranging from –5.05 to 5.66 g/100 g. In contrast, Eq. [8], [13], and [16] were developed from a meta-analysis by Paulk et al. (2015) and included multiple predictive factors involving diet lipid composition, feeding days, NE content of diets, live growth performance criteria, and carcass composition. Therefore, it is reasonable to expect that adding these additional predictors may improve the prediction of IV because they more broadly account for the variation in dietary energy concentration as well as changes in diet composition that affect the intake and metabolic utilization of dietary lipids by pigs. The results of this study suggest that Eq. [8] increased the precision and accuracy of prediction for BF compared with equations using single predictors. However, limited improvement was observed when Eq. [13] and [16] were used to predict jowl and belly fat IV, respectively. In addition, previous researchers have reported a linear relationship between carcass fat IV and the percentage of DDGS inclusion in diets (Cromwell et al., 2011; Estrada Restrepo, 2013); however, predictions using Eq. [5], [7], [12], and [15] had larger PE and bias than the other equations regardless of fat depot.

**Table 12.** Comparison of prediction equations for the average iodine value (IV; g/100 g) of backfat, jowl fat, and belly fat

Item	Present experiment				Wu (2015) <sup>1</sup>				PE <sup>3</sup>	Bias <sup>4</sup>
	10.7% EE DDGS <sup>2</sup>	5.6% EE DDGS <sup>2</sup>	14.2% EE DDGS <sup>2</sup>	16.0% EE DDGS <sup>2</sup>	CON	LOW	MED	HIGH		
Observed IV	71.38	70.71	72.46	82.15	60.03	72.02	72.88	77.42	–	–
Predicted IV <sup>5</sup>										
Eq. [17]	70.74	65.71	73.50	75.20	63.34	66.99	69.65	76.05	3.93	–2.23
Eq. [18]	67.93	64.43	69.60	70.67	62.68	65.30	67.26	71.97	6.17	–4.90

<sup>1</sup>Previous experiment that was conducted in the same facility with the same genetic line of pigs and followed the same experimental procedures as the present experiment. CON = corn-soybean meal control diet, LOW = 40% low-oil (5.9%) distillers dried grains with solubles (DDGS) diet, MED = 40% medium-oil (9.9%) DDGS diet, and HIGH = 40% high-oil (14.2%) DDGS diet.

<sup>2</sup>Diets containing 40% DDGS from different sources with 10.7, 5.6, 14.2, or 16.0% ether extract (EE; as-fed) content.

<sup>3</sup>Prediction error.

<sup>4</sup>Prediction bias (smaller absolute value indicates greater accuracy of the equation; negative value indicates underestimation and positive value indicates overestimation).

<sup>5</sup>Prediction equations are presented in Table 5.

This was not surprising because the equations based on dietary inclusion rate of DDGS did not account for the variability in oil concentration among DDGS sources. Interestingly, directly relating the EE content of the 7 DDGS sources to the IV of BF using simple linear regression models resulted in a poor fit and was not significant (BF IV = 65.9 + 0.762 × EE% of DDGS;  $R^2 = 0.42$ ;  $P = 0.12$ ). Digestibility of oil content can vary from 52.7 to 81.2% among DDGS sources (Kerr et al., 2013); so, it seems logical that the digestibility of dietary lipid should also be considered as a factor to accurately and precisely predict the carcass fat IV of pigs fed high dietary levels of DDGS in future models.

In summary, reduced oil content of DDGS generally decreased the negative impact of feeding DDGS diets on pork fat quality by lowering the IV of pork fat depots. However, the magnitude of this improvement is not proportional to the amount of change in dietary lipid intake and may be affected by the digestibility of oil in DDGS. Fatty acid composition varies among carcass fat depots, with jowl fat having greater IV than BF and belly fat, but BF appears to be more sensitive to the changes in dietary lipid content. The use of published carcass fat IV prediction equations results in variable precision and accuracy in estimating the IV of carcass fat depots. In general, including additional factors, such as dietary energy content, growth performance, and carcass composition measures, appears to provide better IV predictions than those that are only based on the characteristics and quantities of dietary lipids. Using the percentage of DDGS in diet as a predictor of carcass fat depot IV results in the poorest prediction.

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