Research Article

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Effects of co-products from the corn-ethanol industry on body composition, retention of protein, lipids and energy, and on the net energy of diets fed to growing or finishing pigs

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Abstract

BACKGROUND: Conventional distillers dried grains with solubles (DDGS-CV), uncooked distillers dried grains with solubles (DDGS-BPX) and high-protein distillers dried grains (HP-DDG) are used in diets for pigs to provide protein and energy. These ingredients may have different effects on body composition and energy retention. Therefore, an experiment was conducted to determine effects of DDGS-CV, DDGS-BPX and HP-DDG on body composition and on retention of protein, lipids, and energy when fed to growing or finishing pigs.

RESULTS: The total organ weight was greater ($P < 0.05$) for finishing pigs fed the HP-DDG diet than for finishing pigs fed the basal diet or the DDGS-CV diet. Finishing pigs fed the DDGS-CV diet had greater ($P < 0.05$) lipid gain than pigs fed the other diets, and the net energy (NE) for DDGS-CV was greater ($P < 0.05$) than for DDGS-BPX, but the NE value of HP-DDG was not different from that of DDGS-CV or DDGS-BPX.

CONCLUSION: Inclusion of up to 30% DDGS or HP-DDG in diets fed to growing or finishing pigs will not affect body composition or the retention of energy, protein and lipids, regardless of the stage of growth of pigs. The NE value of DDGS-BPX and HP-DDG is not affected by the stage of growth of pigs, but the NE value of DDGS-CV is greater in finishing than in growing pigs.

Keywords: body composition; distillers dried grains with solubles; energy, high-protein distillers dried grains; pigs; stage of growth

INTRODUCTION

Corn distillers dried grains with solubles (DDGS) and high-protein distillers dried grains (HP-DDG) are produced when corn is used in the fuel ethanol industry and may be used as sources of protein and energy in diets fed to swine.[1] High-protein distillers dried grains were produced when a different fractionation technology was developed by Buhler Inc. (Minneapolis, MN, USA) to more efficiently produce ethanol from corn.[2] Previous research indicates that dietary DDGS sometimes reduces dressing percentage.[3] It is therefore possible that inclusion of DDGS or HP-DDG in diets fed to pigs affects body composition, retention of lipids, protein and energy, and possibly the weights of viscera and internal organs; however, no data have been reported to verify this hypothesis.

Conventional DDGS (DDGS-CV) is produced by grinding and cooking corn using external heat to gelatinize the starch prior to fermentation.[4] The cooking step may be eliminated if enzymes are used to pre-digest the starch prior to fermentation, and DDGS produced using this process is called DDGS-BPX.[4] The gross composition of DDGS-BPX is similar to the composition of DDGS-CV, but digestible energy (DE) and metabolizable energy (ME) in DDGS-BPX is less than in DDGS-CV.[5] It is, however, not known if the NE value is also different between the two sources of DDGS.

The DE and ME in HP-DDG may be greater than in corn;[2,6] however, data for the NE of HP-DDG have not been reported. The NE of corn is greater for finishing than for growing pigs because finishing pigs retain more lipids than growing pigs;[7] however, it is not known if the NE value of DDGS and HP-DDG is greater for finishing than for growing pigs. The objective of this experiment, therefore, was to test the hypothesis that inclusion of DDGS-CV, DDGS-BPX, or HP-DDG in diets fed to pigs does not influence body composition, organ weight, or nutrient and energy retention. The second objective was to determine if differences in the NE value among DDGS-CV, DDGS-BPX and HP-DDG exist, and if the NE of these ingredients is different between growing and finishing pigs.

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EXPERIMENTAL

The protocol for the experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois.

Animals, housing and experimental design

Fifty-two growing and 52 finishing barrows originating from the matings of line 337 sires to C-22 females (Pig Improvement Company, Hendersonville, TN, USA) were used. The average initial body weight (BW) was 20.8 ± 2.06 kg and 87.2 ± 9.77 kg for the growing and finishing pigs, respectively. Pigs were selected from a larger pool of pigs that had been monitored for average daily gain (ADG) during a 2-week pre-experimental period. Pigs within each stage of growth were fed the same corn–soybean meal-based diet during this period and pigs that were relatively close in ADG were selected for the experiment. Within each stage of growth, pigs were randomly allotted to six groups with two groups of eight pigs and four groups of nine pigs based on their initial BW. The two groups with eight pigs at each stage of growth served as the initial slaughter group and all pigs in these two groups were harvested at the start of the experiment. The remaining four groups within each stage of growth were randomly assigned to four dietary treatments. The experimental period was 28 days for growing pigs and 35 days for finishing pigs, and all pigs were harvested at the conclusion of the experiment. Pigs were housed individually in 0.9 × 1.8 m pens in an environmentally controlled building. Pens were equipped with a fully slatted concrete floor, a feeder, and a bowl-shaped nipple drinker.

Dietary treatments, feeding, slaughter and sample collections

Commercial sources of corn and soybean meal were used. Conventional DDGS was obtained from Lincolnland Agri-Energy, LLC (Palestine, IL, USA), and DDGS-BPX and HP-DDG were obtained from Poet Nutrition (Sioux Falls, SD, USA; Table 1). The same batch of each ingredient was used to mix diets for growing and finishing pigs.

Four diets at each stage of growth were formulated (Table 2). The basal diet contained mainly corn and soybean meal. Vitamins and micro minerals were included in the basal diet to exceed estimated nutrient requirements[8] of pigs at each stage of growth. Three additional diets were prepared by mixing 70% of the basal diet and 30% DDGS-BPX, DDGS-CV or HP-DDG. All diets were provided in a meal form and met the requirement of nutrients for growing and finishing pigs.[8] Pigs were allowed ad libitum access to feed and water throughout the experiment. Feed samples were collected weekly and pooled at the conclusion of the experiment. A sample of each of the ingredients was collected before diets were mixed.

The BW of each pig was recorded at the initiation of the experiment and at the end of each week thereafter. Daily feed allowances were recorded for each pig and feed left in the feeders was recorded on the same day the BW of pigs was recorded. All procedures for feeding, recordings of pig BW, pig slaughter and sample collections were similar to those described by Kil.[9] Briefly, pigs were weighed at the last day of the experiment. Feed was then withheld for 16 h, and pigs were transported to the Meat Science Laboratory at the University of Illinois, where pigs were weighed again and euthanized to collect samples. Samples were also lyophilized, subsampled and analyzed as previously outlined,[10] using AOAC procedures.[11] Ingredients and diet samples were also analyzed for starch, total dietary fiber and amino acids (AA).[11]

Table 1. Analyzed composition of corn, soybean meal, distillers dried grains with solubles (DDGS) and high-protein distillers dried grains (HP-DDG), as fed basis

Composition	Ingredient[a]				
	Corn	Soybean meal, 48%	DDGS-BPX	DDGS-CV	HP-DDG
Dry matter (g kg^{-1})	885	902	888	898	919
Gross energy (MJ kg^{-1})	16.41	18.09	20.43	20.98	20.98
Crude protein (g kg^{-1})	85	487	272	284	405
Ether extract (g kg^{-1})	20	112	26	130	31
AEE[b] (g kg^{-1})	35	22	132	142	61
Ash (g kg^{-1})	11	76	58	48	24
Total starch (g kg^{-1})	616	9	34	33	41
Total dietary fiber (g kg^{-1})	86	130	288	285	281
Indispensable amino acids (g kg^{-1})					
Arginine	3.9	35.8	12.6	12.8	14.5
Histidine	2.3	12.6	7.5	7.5	10.5
Isoleucine	3.0	24.2	11.6	11.4	17.9
Leucine	9.6	37.8	30.4	31.9	56.3
Lysine	2.6	30.8	9.8	8.7	10.9
Methionine	1.8	6.8	5.2	5.5	8.4
Phenylalanine	3.9	24.9	13.0	13.4	22.1
Threonine	2.7	18.1	9.8	9.7	14.0
Tryptophan	0.6	7.0	1.6	2.3	2.2
Valine	3.8	24.0	13.7	13.6	20.1
Dispensable amino acids (g kg^{-1})					
Alanine	5.8	20.6	18.0	18.5	30.3
Aspartic acid	5.3	54.1	16.9	16.4	24.2
Cysteine	1.8	7.3	5.6	5.5	7.7
Glutamic acid	14.5	85.8	38.2	37.5	66.9
Glycine	3.1	20.5	10.7	10.6	13.1
Proline	6.7	24.9	20.9	19.7	34.8
Serine	3.4	20.4	11.0	11.3	16.5
Tyrosine	2.4	17.5	9.9	9.7	16.8
Total amino acid (g kg^{-1})	78.1	474.7	247.7	247.3	389.9

[a] DDGS-BPX, distillers dried grains with solubles from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD, USA); DDGS-CV, conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC, Palestine, IL, USA); HP-DDG, high-protein distillers dried grains (Poet Nutrition, Sioux Falls, SD, USA).
[b] AEE, acid hydrolyzed ether extract.

Calculations

Data for average daily feed intake (ADFI), ADG and gain:feed (G:F) were calculated and summarized within each treatment and within each stage of growth. For all pigs at each stage of growth, BW was recorded before slaughter. The dressing percentage for each pig was calculated by dividing the hot carcass weight (HCW, kg) by the live BW (kg). The total weight of harvested pigs was calculated as follows:

$$\text{total weight} = \text{HCW} + B + V_{\text{f}} + O$$

where B is blood weight (kg), V_{f} is the weight of the full viscera (kg) and O is organ weight (kg), which includes kidneys, heart, liver, lungs and spleen. The total digesta-free BW was calculated as follows:

$$\text{total digesta} - \text{free BW} = \text{CCW} + B + V_{\text{e}} + O$$

Table 2. Composition (as fed basis) of experimental diets containing uncooked distillers dried grains with solubles (DDGS-BPX), conventional distillers dried grains with solubles (DDGS-CV), or high-protein distillers dried grains (HP-DDG)

	Growing pigs				Finishing pigs			
Item	Basal	DDGS-BPX	DDGS-CV	HP-DDG	Basal	DDGS-BPX	DDGS-CV	HP-DDG
Ingredient (g kg^{-1})								
Ground corn	661.0	462.7	462.7	462.7	800.0	560.0	560.0	560.0
Soybean meal, 48%	280.0	196.0	196.0	196.0	165.0	115.5	115.5	115.5
DDGS-BPX	–	300.0	–	–	–	300.0	–	–
DDGS-CV	–	–	300.0	–	–	–	300.0	–
HP-DDG	–	–	–	300.0	–	–	–	300.0
Soybean oil	20.0	14.0	14.0	14.0	–	–	–	–
Limestone	15.0	10.5	10.5	10.5	15.0	10.5	10.5	10.5
Monocalcium phosphate	7.0	4.9	4.9	4.9	6.0	4.2	4.2	4.2
Cr_2O_3	5.0	3.5	3.5	3.5	5.0	3.5	3.5	3.5
Vitamin-mineral premix	4.5	3.2	3.2	3.2	4.0	2.8	2.8	2.8
Salt	6.0	4.2	4.2	4.2	5.0	3.5	3.5	3.5
Tylan® Premix[a]	1.5	1.1	1.1	1.1	–	–	–	–
Energy and nutrients[b]								
Dry matter (g kg^{-1})	877	894	887	896	884	890	892	899
Gross energy (MJ kg^{-1})	16.50	17.99	18.05	17.97	15.81	16.69	16.83	17.33
Metabolizable energy (MJ kg^{-1})	14.15	14.20	14.20	15.10	13.79	13.94	13.94	14.85
Crude protein (g kg^{-1})	204	214	221	260	144	188	185	219
Ether extract (g kg^{-1})	40	65	69	41	30	55	66	30
AEE[c] (g kg^{-1})	49	79	81	55	37	68	74	52
Ash (g kg^{-1})	63	58	56	48	48	50	48	40
Total starch (g kg^{-1})	418	300	294	313	476	342	342	356
Total dietary fiber (g kg^{-1})	107	159	142	155	103	166	160	167
Ca (g kg^{-1})	8.0	6.2	6.2	5.7	7.5	5.9	5.9	5.3
Bioavailable P (g kg^{-1})	2.4	2.7	2.7	2.0	1.6	2.5	2.5	1.7
SID[d] methionine (g kg^{-1})	27	32	32	41	22	28	29	37
SID lysine (g kg^{-1})	89	81	79	85	61	60	58	65
SID threonine (g kg^{-1})	57	61	60	71	42	50	50	61
SID tryptophan (g kg^{-1})	21	18	20	20	14	13	15	15

[a] The Tylan premix (Elanco Animal Health, Indianapolis, IN, USA) provided 40 mg kg^{-1} tylosine phosphate to the diets.
[b] Values for metabolizable energy, Ca, bioavailable P, SID methionine, SID lysine, SID threonine and SID tryptophan were calculated (NRC, 1998, 2012); all other values were analyzed.
[c] AEE, acid hydrolyzed ether extract.
[d] SID, standardized ileal digestible.

where CCW is the chilled carcass weight (kg), and V_e is empty viscera weight (kg). The CCW was recorded after the carcass had been stored in a cooler at 4 °C for 16 h.

For each pig, the total concentration of energy, protein and lipids at harvest was calculated from the sum of energy, protein and lipids in carcass, viscera and blood. Retention of energy, protein and lipids during the experimental period was calculated for each pig from the difference between the final concentration of energy, protein and lipids at harvest and the estimated initial concentration of energy, protein and lipids.[12] The initial body composition of the experimental pigs was determined from the body composition of pigs in the initial slaughter group.[13] The following equation was used for this calculation:

$$\mathrm{TBi} = \mathrm{LW} \times \mathrm{ISGi}$$

where TBi is the total concentration of energy, protein, or lipids in the body at the start of the experiment, LW is the initial live weight (kg) of the experimental pigs recorded prior to slaughter and ISGi is the average concentration (MJ kg^{-1} or g kg^{-1}) of energy, protein or lipids that was measured in the pigs in the initial slaughter group. Energy retention was also calculated by multiplying protein gain (g) and lipid gain (g) by 23.70 and 39.61 MJ kg^{-1}, respectively.[14]

The NE requirement for maintenance for each pig was calculated by multiplying the mean metabolic BW ($kg^{0.6}$) by 0.75 MJ.[15] The NE value of each diet was calculated as the sum of the energy retained in the body and the total NE requirement for maintenance during the experimental period.[14] The NE value of DDGS-BPX, DDGS-CV and HP-DDG were subsequently calculated using the difference procedure by subtracting the NE contribution by the basal diet from the NE of the diets containing DDGS-BPX, DDGS-CV or HP-DDG.[12]

Statistical analyses

All data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC, USA) with the individual pig as the experimental unit. Normality of data was verified using the UNIVARIATE procedure of SAS. Diet was the fixed effect and outcome group was the random effect in the model. The differences among treatments were determined using analysis of variance, and the means were separated using the LS means statement and the PDIFF option with adjustment for the Tukey–Kramer test. An alpha-value of 0.05 was used to assess significance among means. The NE value for each ingredient was also compared between growing pigs and finishing pigs.

RESULTS

The ADG, ADFI and G:F for both growing pigs and finishing pigs were not affected ($P > 0.05$) by dietary treatments (Table 3). In growing pigs, the live BW recorded prior to slaughter, HCW, chilled carcass weight, total weight and total digesta-free BW were greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the DDGS-BPX diet (Table 4). In finishing pigs, dressing percentage was greater ($P < 0.05$) for pigs fed the basal and DDGS-CV diets than for pigs fed the HP-DDG diet (Table 5). Total organ weight was greater ($P < 0.05$) for pigs fed the HP-DDG diet than for pigs fed the DDGS-CV diet.

In growing pigs, the concentration of protein in the total digesta-free BW was greater ($P < 0.05$) for pigs fed the DDGS-BPX diet than for pigs fed the HP-DDG diet (Table 6). The total amount of protein retained in the body and the protein gain was also greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the DDGS-CV or HP-DDG diets.

In finishing pigs, the concentration of lipids in total digesta-free BW, lipid gain, measured energy retention (MER) and calculated energy retention (CER) were greater ($P < 0.05$) for pigs fed the DDGS-CV diet than for pigs fed the DDGS-BPX diet (Table 7). The concentration of energy in the total digesta-free BW was greater ($P < 0.05$) for pigs fed the DDGS-CV diet than for pigs fed the DDGS-BPX diet or the HP-DDG diet, and concentration of energy in the total digesta-free BW of pigs fed the basal diet was greater ($P < 0.05$) than in pigs fed the DDGS-CV diet.

In growing pigs, the NE value was 8.23 MJ kg^{-1} for the basal diet, 8.13 MJ kg^{-1} for the DDGS-BPX diet, 8.21 MJ kg^{-1} for the DDGS-CV diet and 8.43 MJ kg^{-1} for the HP-DDG diet (Table 8). The NE values for DDGS-BPX, DDGS-CV and HP-DDG were 7.80 MJ kg^{-1}, 8.17 MJ kg^{-1} and 8.90 MJ kg^{-1}, respectively. In finishing pigs, the NE value was 8.15, 8.00, 8.78 and 8.19 MJ kg^{-1} for the basal diet, DDGS-BPX diet, DDGS-CV diet and HP-DDG diet, respectively. The NE value of DDGS-CV was, however, greater ($P < 0.05$) than the NE value of DDGS-BPX (10.39 vs.7.51 MJ kg^{-1}), but not different from the NE value of DDGS-BPX (8.43 MJ kg^{-1}). The NE value of DDGS-BPX and HP-DDG was not different ($P > 0.05$) between growing and finishing pigs, but the NE value of DDGS-CV was less ($P < 0.01$) for growing than for finishing pigs (Table 9).

Table 3. Effects of treatments on growth performance of growing and finishing pigs[a]

Item	Diet[b] Basal	DDGS-BPX	DDGS-CV	HP-DDG	SEM	*P*-value
Growing pigs (28 days)						
ADG[c] (kg)	0.973	0.890	0.898	0.868	0.04	0.21
ADFI[c] (kg)	1.887	1.664	1.724	1.719	0.08	0.15
G:F[c]	0.518	0.536	0.521	0.507	0.02	0.53
Finishing pigs (35 days)						
ADG[c] (kg)	1.195	1.073	1.160	1.103	0.06	0.43
ADFI[c] (kg)	3.451	3.083	3.267	3.098	0.16	0.17
G:F[c]	0.347	0.347	0.356	0.358	0.01	0.81

[a] Data are least squares means. In growing pigs $n = 7$ for basal, $n = 8$ for DDGS-BPX, $n = 9$ for DDGS-CV and HP-DDG. In finishing pigs $n = 9$ for basal, $n = 8$ for DDGS-BPX, DDGS-CV and HP-DDG.
[b] DDGS-BPX, distillers dried grains with soluble from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD, USA); DDGS-CV, conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC, Palestine, IL, USA); HP-DDG, high-protein distillers dried grains (Poet Nutrition, Sioux Falls, SD USA).
[c] ADG, average daily gain; ADFI, average daily feed intake; G:F, gain:feed.

DISCUSSION

Growth performance

The observation that no differences in growth performance between pigs fed the diets containing 30% corn co-products and pigs fed the control diet agrees with results of many previous experiments.[16–19] A decrease in ADG and ADFI as the inclusion of DDGS in the diet increases has, however, also been reported from some experiments.[20–22] This inconsistency among experiments may be a result of different qualities of DDGS used, because AA digestibility, DE and ME values may vary among sources of DDGS.[23,24] Widmer *et al.*[25] observed reduced ADG and ADFI if 40% HP-DDG was included in the diet fed to growing pigs, but not if 20% was used. Inclusion of HP-DDG does not, however, affect growth performance of finishing pigs,[2,25] and the current results are in agreement with these observations. Because the substitution procedure was used in this experiment, it was also necessary to formulate diets that were not exactly equal in nutrient composition. It is, however, unlikely that the small differences in diet nutrient composition impacted growth performance of the pigs, because all diets were formulated to contain nutrients in quantities that met or exceeded the requirements of the animals regardless of which diet they were fed.[8]

Body composition

The observation that dressing percentage was not affected by inclusion of DDGS in the diets in the present experiment is in agreement with many previous experiments,[3] although it has been suggested that increased concentrations of dietary fiber may reduce dressing percentage.[26]

The reduction in dressing percentage that was observed for finishing pigs fed the HP-DDG diet was surprising. It is possible that it is the increased crude protein (CP) rather than the dietary fiber that may have been responsible for the reduced dressing percentage of pigs fed the HP-DDG diet. This hypothesis is supported by the observation that the weights of total organs were greater in finishing pigs fed the HP-DDG diet compared with pigs fed the basal diet. The increased weight of total organs expressed as a percentage of empty BW in growing pigs fed the HP-DDG diet compared with pigs fed the basal diet also supports this hypothesis. An increase in dietary CP concentration may affect the size of some of the internal organs, such as stomach, kidneys and liver,[27,28] and an increase in the weight of the liver as a result of increased dietary CP has been previously reported and is a result of increased urea cycle activity.[29] It is therefore likely that the increased weights of total organs in pigs fed the HP-DDG diet is a result of increased metabolic load due to the increased concentration of CP in the diet. We are not aware of other reports on the effects of feeding DDGS or HP-DDG on organ weights. Based on the results obtained in the present experiment, we hypothesize that one of the reasons for the reduced dressing percentages that is sometimes observed

Table 4. Weights of carcass and body components of growing pigs[a]

	Diet[b]					
	Basal	DDGS-BPX	DDGS-CV	HP-DDG	SEM	*P*-value
Live weight (kg)	44.8y	40.5x	41.9xy	42.0xy	1.1	0.01
Hot carcass weight (kg)	35.0y	31.5x	32.8xy	32.8xy	1.0	0.01
Dressing percentage (%)	78.1	77.7	78.1	78.0	0.6	0.94
Chilled carcass weight (kg)	34.5y	31.0x	32.4xy	32.4xy	1.0	0.01
Blood weight (kg)	2.18	2.00	2.02	1.99	0.09	0.26
Full viscera weight (kg)	4.83	4.54	4.61	4.51	0.19	0.56
Full viscera weight (% of live weight)	10.7	11.2	11.0	10.8	0.4	0.80
Empty viscera weight (kg)	3.57	3.33	3.45	3.44	0.14	0.57
Empty viscera weight (% of live weight)	7.94	8.27	8.22	8.22	0.26	0.75
Liver weight (kg)	1.08	1.00	1.02	1.08	0.04	0.26
Heart weight (kg)	0.21	0.20	0.21	0.20	0.01	0.34
Kidney weight (kg)	0.29	0.27	0.29	0.27	0.01	0.35
Lungs weight (kg)	0.51	0.58	0.58	0.63	0.04	0.15
Spleen weight (kg)	0.10	0.10	0.11	0.10	0.01	0.75
Total organ weight[c] (kg)	2.19	2.13	2.21	2.29	0.08	0.33
Total viscera + organ weight (kg)	5.76	5.47	5.66	5.73	0.20	0.58
Total weight[d] (kg)	44.2y	40.1x	41.6xy	41.6xy	1.2	0.01
Total digesta-free body weight[e] (kg)	42.5y	38.5x	40.1xy	40.1xy	1.1	0.01

Means within a row lacking a common letter (x, y) are different ($P < 0.05$).
[a] Data are least squares means; $n = 8$ for basal, $n = 7$ for DDGS-BPX, $n = 9$ for DDGS-CV and HP-DDG.
[b] DDGS-BPX, distillers dried grains with soluble from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD, USA); DDGS-CV, conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC, Palestine, IL, USA); HP-DDG, high-protein distillers dried grains (Poet Nutrition, Sioux Falls, SD, USA).
[c] Total organ weight = sum of the weights of liver, heart, kidney, lungs and spleen.
[d] Total weight = sum of hot carcass weight, and the weights of blood, full viscera and total organ weight.
[e] Digesta-free body weight is the sum of the weight of the chilled carcass, empty viscera and blood.

Table 5. Weights of carcass and body components of finishing pigs[a]

	Diet[b]					
	Basal	DDGS-BPX	DDGS-CV	HP-DDG	SEM	*P*-value
Live weight (kg)	119.7	119.3	118.8	119.3	4.0	0.99
Hot carcass weight (kg)	100.8	99.9	100.3	98.4	3.6	0.88
Dressing percentage (%)	84.2y	83.6xy	84.4y	82.5x	0.5	0.01
Chilled carcass weight (kg)	100.2	99.0	99.6	97.7	3.6	0.87
Blood weight (kg)	4.35	4.53	4.20	4.47	0.17	0.57
Full viscera weight (kg)	9.30	9.48	9.20	10.51	0.48	0.14
Full viscera weight (% of live weight)	7.76	7.98	7.75	8.83	0.32	0.08
Empty viscera weight (kg)	6.08	6.30	6.18	6.56	0.61	0.29
Empty viscera weight (% of live weight)	4.98	5.21	5.15	5.41	0.46	0.22
Liver weight (kg)	1.82	1.89	1.79	2.00	0.07	0.09
Heart weight (kg)	0.44	0.43	0.45	0.44	0.02	0.87
Kidney weight (kg)	0.46	0.46	0.45	0.50	0.02	0.14
Lungs weight (kg)	1.46	1.54	1.42	1.62	0.11	0.55
Spleen weight (kg)	0.22	0.22	0.21	0.22	0.01	0.64
Total organ weight[c] (kg)	4.39xy	4.54xy	4.31x	4.78y	0.12	0.04
Total viscera + organ weight (kg)	10.5	10.9	10.5	11.3	0.7	0.06
Total weight[d] (kg)	118.9	118.5	118.0	118.2	4.0	1.00
Total digesta-free body weight[e] (kg)	115.0	114.4	114.3	113.5	4.2	0.97

Means within a row lacking a common letter (x, y) are different ($P < 0.05$).
[a] Data are least squares means; $n = 9$ for basal, $n = 8$ for DDGS-BPX, DDGS-CV and HP-DDG.
[b] DDGS-BPX, distillers dried grains with soluble from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD, USA); DDGS-CV, conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC, Palestine, IL, USA); HP-DDG, high-protein distillers dried grains (Poet Nutrition, Sioux Falls, SD, USA).
[c] Total organ weight = sum of the weights of liver, heart, kidney, lungs and spleen.
[d] Total weight = sum hot carcass weight, and the weights of blood, full viscera, liver, heart, kidney, lungs and spleen.
[e] Digesta-free BW is the sum of the weight of the chilled carcass, empty viscera and blood.

Table 6. Effects of feeding distillers dried grains with solubles (DDGS) and high-protein distillers dried grains (HP-DDG) on body composition and retention of energy, protein and lipids in growing pigs[a]

Item	ISG[b]	Diet[c] Basal	DDGS-BPX	DDGS-CV	HP-DDG	SEM	P-value
Body composition							
Total digesta-free body weight[d] (kg)	19.64 ± 1.81	42.47y	38.50x	40.12xy	40.08xy	1.08	0.01
Total digesta-free body weight (kg dry matter)	5.64 ± 0.68	14.69	13.09	13.64	13.62	0.54	0.11
Protein (g kg^{-1} dry matter)	576 ± 24.2	500xy	516y	482xy	472x	9.2	0.01
Lipid (g kg^{-1} dry matter)	277 ± 29.8	404	397	375	412	14.8	0.31
Energy (MJ kg^{-1} dry matter)	24 ± 0.71	27	26	26	27	0.29	0.34
Total protein (kg per pig)	3.24 ± 0.35	7.33y	6.79xy	6.55x	6.42x	0.23	0.01
Total lipid (kg per pig)	1.58 ± 0.33	5.95	5.23	5.17	5.64	0.39	0.38
Total energy (MJ per pig)	138 ± 19.7	396	346	360	366	17	0.15
Retention							
Protein gain (g d^{-1})	–	150y	130xy	122x	117x	6	0.01
Lipid gain (g d^{-1})	–	159	133	130	147	13	0.38
Lipid gain:protein gain (g g^{-1})	–	1.06	1.01	1.05	1.25	0.08	0.13
MER[e] (MJ d^{-1})	–	9.41	7.61	8.08	8.28	0.54	0.15
CER[f] (MJ d^{-1})	–	9.83	8.33	8.03	8.58	0.63	0.19

Means within a row lacking a common letter (x, y) are different ($P < 0.05$).
[a] Data are least squares means; $n = 16$ for initial slaughter group, $n = 8$ for basal, $n = 7$ for DDGS-BPX, $n = 9$ for DDGS-CV and HP-DDG.
[b] ISG, initial slaughter group. Initial slaughter group was not included in analysis.
[c] DDGS-BPX, distillers dried grains with soluble from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD, USA); DDGS-CV, conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC, Palestine, IL, USA); HP-DDG, high-protein distillers dried grains (Poet Nutrition, Sioux Falls, SD, USA).
[d] Digesta-free BW is the sum of the weight of the chilled carcass, empty viscera and blood.
[e] MER, measured energy retention.
[f] CER, calculated energy retention (calculated from protein and lipid gain as 23.70 and 39.61 MJ kg^{-1} for protein and lipids, respectively).[14]

Table 7. Effects of feeding distillers dried grains with solubles (DDGS) and high-protein distillers dried grains (HP-DDG) on body composition and retention of energy, protein and lipids in finishing pigs[a]

Item	ISG[b]	Dietary treatment Basal	DDGS-BPX	DDGS-CV	HP-DDG	SEM	P-value
Body composition							
Total digesta-free body weight[d] (kg)	82.96 ± 7.40	115.46	114.86	114.74	113.96	3.81	0.98
Total digesta-free body weight (kg dry matter)	33.88 ± 4.12	50.12	49.03	51.44	49.06	2.11	0.64
Protein (g kg^{-1} dry matter)	400 ± 22.3	364	382	348	372	10.0	0.14
Lipid (g kg^{-1} dry matter)	509 ± 29.9	547xy	512x	564y	530xy	10.4	0.01
Energy (MJ kg^{-1} dry matter)	29 ± 0.59	30yz	29x	30z	29xy	0.21	0.01
Total protein (kg per pig)	13.48 ± 1.24	18.12	18.47	17.80	18.10	0.63	0.78
Total lipid (kg per pig)	17.32 ± 2.73	27.57	25.27	29.04	26.05	1.49	0.14
Total energy (MJ per pig)	985 ± 131.0	1,503	1,426	1,543	1,439	69	0.32
Retention							
Protein gain (g d^{-1})	–	147	140	132	135	10	0.78
Lipid gain (g d^{-1})	–	312xy	220x	346y	253xy	30	0.02
Lipid gain:protein gain (g g^{-1})	–	2.25	1.60	2.98	1.90	0.36	0.07
MER[e] (MJ d^{-1})	–	15.90xy	12.22x	16.48y	13.10xy	1.17	0.03
CER[f] (MJ d^{-1})	–	15.82xy	11.97x	16.82y	13.18xy	1.17	0.02

Means within a row lacking a common letter (x, y) are different ($P < 0.05$).
[a] Data are least squares means; $n = 16$ for initial slaughter group, $n = 9$ for basal, $n = 8$ for DDGS-BPX, DDGS-CV and HP-DDG.
[b] ISG, initial slaughter group. Initial slaughter group was not included in analysis.
[c] DDGS-BPX, distillers dried grains with soluble from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD, USA); DDGS-CV, conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC, Palestine, IL, USA); HP-DDG, high-protein distillers dried grains (Poet Nutrition, Sioux Falls, SD, USA).
[d] Digesta-free BW is the sum of the weight of the chilled carcass, empty viscera and blood.
[e] MER, measured energy retention.
[f] CER, calculated energy retention (calculated from protein and lipid gain as 23.70 and 39.61 MJ kg^{-1} for protein and lipids, respectively).[14]

Table 8. Net energy of diets and ingredients fed to growing and finishing pigs[a]

	Dietary treatment[b]					
Item	Basal	DDGS-BPX	DDGS-CV	HP-DDG	SEM	*P*-value
Growing pigs						
Initial body energy (MJ)	132.9	134.5	133.5	133.5	4.5	0.87
Final body energy (MJ)	395.9	346.0	359.5	366.0	17.4	0.15
Energy retention (MJ)	263.3	213.0	226.0	232.4	15.7	0.15
Total NE_m[c] (MJ)	170.9	167.2	169.2	168.8	2.7	0.53
Total NE intake[d] (MJ)	434.1	379.7	395.3	404.7	17.9	0.16
Total feed intake (kg)	52.8	46.9	48.1	48.1	2.0	0.16
NE of diets (MJ kg^{-1})	8.23	8.13	8.21	8.43	0.18	0.67
NE of ingredient[e] (MJ kg^{-1})	–	7.80	8.17	8.90	0.63	0.39
Finishing pigs						
Initial body energy (MJ)	946.8	998.2	964.6	979.1	37.8	0.30
Final body energy (MJ)	1,503.0	1,425.9	1,543.6	1,439.0	69.4	0.32
Energy retention (MJ)	556.1xy	426.9x	577.5y	458.4xy	41.1	0.03
Total NE_m[c] (MJ)	428.2	430.5	430.0	429.6	9.2	0.99
Total NE intake[d] (MJ)	984.3	857.5	1,008.2	888.7	47.7	0.06
Total feed intake (kg)	120.8	107.9	114.4	108.4	5.5	0.17
NE of diets (MJ kg^{-1})	8.15	8.00	8.78	8.19	0.25	0.17
NE of ingredient[e] (MJ kg^{-1})	–	7.51x	10.39y	8.43xy	0.87	0.02

Means within a row lacking a common letter (x, y) are different ($P < 0.05$).
[a] Data are least squares means. In growing pigs $n = 7$ for basal, $n = 8$ for DDGS-BPX, $n = 9$ for DDGS-CV and HP-DDG. In finishing pigs $n = 9$ for basal, $n = 8$ for DDGS-BPX, DDGS-CV and HP-DDG.
[b] DDGS-BPX, distillers dried grains with solubles from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD, USA); DDGS-CV, conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC, Palestine, IL, USA); HP-DDG, high-protein distillers dried grains (Poet Nutrition, Sioux Falls, SD, USA).
[c] Total net energy (NE) requirement for maintenance.
[d] Total NE intake = energy retention plus total NE_m.
[e] NE of DDGS-BPX, DDGS-CV or HP-DDG.

Table 9. Comparison of NE (MJ kg^{-1}) for ingredients between growing and finishing pigs[a]

Ingredient[b]	Growing	Finishing	SEM	*P*-value
DDGS-BPX	7.90	7.67	1.00	0.87
DDGS-CV	8.17	10.14	0.45	0.01
HP-DDG	8.90	8.18	0.76	0.52

[a] Data are least squares means.
[b] DDGS-BPX, distillers dried grains with soluble from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD, USA); DDGS-CV, conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC, Palestine, IL, USA); HP-DDG, high-protein distillers dried grains (Poet Nutrition, Sioux Falls, SD, USA).

when DDGS or HP DDG is included in diets fed to pigs may be that concentrations of CP is increased in these diets.

Retention of energy and nutrients and NE values of diets and ingredients

The protein gains for growing and finishing pigs fed the basal diet in this experiment are similar to values reported by Quiniou *et al.*[30] It was, however, surprising that growing pigs fed the HP-DDG diet had a reduced concentration of CP in body dry matter compared with pigs fed the DDGS-BPX diet. This observation indicates that growing pigs fed the HP-DDG diet utilized the CP in the diet less efficiently than pigs fed the other diets. It is possible that this is a result of heat damage to the HP-DDG because the Lys:CP ratio, which can be used as an indicator of heat damage in feed ingredients,[31] was only 2.69% for the HP-DDG used in this experiment. The ratio, however, was 3.60% for the DDGS-BPX used in this experiment and the ratio was between 2.94 and 2.99% in the HP-DDG used in previous experiments.[2,6] It has been reported that heat damage has negative effects on the concentration of lysine and digestibility of lysine by converting some of the lysine to undigestible Maillard reaction products.[31] It is, therefore, likely that the reduced retention of CP in the pigs fed the HP-DDG diet is a result of lysine deficiency caused by heat damage to HP-DDG.

The lack of any differences among finishing pigs fed experimental diets in protein gain or protein concentration in digesta-free BW indicates that, regardless of dietary treatment, finishing pigs had sufficient quantities of indispensable AA to meet the requirement for maximum protein synthesis. The increased lipid and energy concentration in the body of pigs fed the DDGS-CV diet compared with pigs fed the DDGS-BPX diet, however, indicates that pigs utilized more energy from DDGS-CV than from DDGS-BPX, which was also reflected in the greater energy retention for pigs fed the DDGS-CV diet compared with pigs fed the DDGS-BPX diet. As a consequence of these differences, the NE value of DDGS-CV was greater than the NE value for DDGS-BPX when fed to finishing pigs. This observation is in agreement with data indicating that DE and ME values in DDGS-BPX are less than in DDGS-CV.[5] No difference was observed between the NE value of the diet containing DDGS-CV and the NE value of the basal diet, which indicates that the NE value of DDGS-CV is similar to that of a combination of corn and soybean meal. This observation is in agreement with data indicating that the DE and ME in DDGS-CV is not different from the DE and ME in corn.[31,32] The NE for growing pigs for DDGS-CV and

DDGS-BPX and the NE value of DDGS-BPX fed to finishing pigs are in agreement with previously published values for DDGS of medium or high quality (8.25 and 8.62 MJ kg^{-1}, respectively[33]), and the NE of DDGS-CV for finishing pigs is close to the value of 9.98 MJ kg^{-1} for DDGS with more than 10% fat that was recently reported.[1]

The NE for HP-DDG that were calculated for growing and finishing pigs (8.90 and 8.18 MJ kg^{-1}, respectively) are less than a recently published value of 9.81 MJ kg^{-1},[1] and that is likely a result of the greater concentration of fiber in the HP-DDG used in the present experiment.

The NE values for the basal diets that were calculated in this experiment are also less than values that can be calculated for a diet based on corn and soybean meal.[1] The main reasons for this observation are most likely that pigs in the present experiment were allowed ad libitum access to feed and that NE values were calculated based on the comparative slaughter procedure, which will result in reduced NE values compared with values determined in restricted fed pigs using the indirect calorimetry procedure.[10,34]

It was expected that finishing pigs would be able to obtain more energy from the ingredients than growing pigs, because finishing pigs have the potential for depositing more lipids than growing pigs and have a larger capacity for fermentation in the hindgut than growing pigs.[7] In the present experiment, however, a greater NE value in finishing pigs than in growing pigs was only observed for DDGS-CV, but not for DDGS-BPX and HP-DDG, which indicates that finishing pigs do not always obtain more energy from feed ingredients than growing pigs. It may be speculated that the reason for this observation is that the DDGS-CV had the greatest concentration of lipids. Finishing pigs had a much greater lipid deposition than growing pigs and the energy value of lipids is greater if it is used for lipid deposition rather than being oxidized for ATP.[35] We did not attempt to determine the metabolic fate of dietary lipids in this experiment so we do not have data to back this hypothesis. The observed MER values were in good agreement with the CER values for both growing and finishing pigs, which indicates that analytical inaccuracies were not responsible for the observation that no difference in NE value of DDGS-BPX and HP-DDG was observed between growing and finishing pigs. Therefore, more research is needed to determine factors that influence differences in NE values between growing and finishing pigs.

CONCLUSIONS

Results of this experiment indicate that pig growth performance, body composition, and the retention of energy and nutrients are not affected by inclusion of DDGS or HP-DDG in the diets. Inclusion of up to 30% DDGS or HP-DDG in a corn–soybean meal diet will not affect the NE value of diets. Differences in production procedures among ethanol plants may influence the NE value of DDGS. Results of the present experiment also indicate that the NE value for feed ingredients is not always greater in finishing pigs than in growing pigs.

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