RESEARCHREPORT
ANIMAL SCIENCE

Title: Oxygen consumption and energy digestibility of soybean meal and corn or corn co-product diets fed to grow-finish swine – **NPB #06-001**

Investigator: Wendy Powers

Institution: Michigan State University

Date Submitted: January 15, 2008

Industry Summary
Diets containing corn or corn co-products were fed to swine over 6 feeding phases, starting at 18 kg bodyweight and concluding at market weight. The corn co-product diets contained increasing levels of the co-product; from 5 to 30% over the course of six feeding phases. Co-products used included distillers dried grains with solubles (DDGs), corn germ meal (CGM), and dehulled, degermed corn (DDC). Findings demonstrated no differences in animal growth or feed intake. However; pigs fed DDC diets had better utilization of diet energy and pigs fed the DDGs diets produced more heat, suggesting that there may have been some compensatory factors that allowed for similar growth to occur across diets. Carcass measures were not made and would need to be considered when deciding if these corn co-products are to be included in an operation's management plan.

Scientific Abstract
A study was conducted to evaluate the energy utilization of diets containing corn or co-products of corn processing. Forty-eight barrows were allocated to one of 4 dietary treatments and housed in closed chambers that allowed for measurement of oxygen consumption and carbon dioxide production. Gas measures were made continuously during the 4-month trial that represented the grow-finish period and contained 6 feeding phases (S1, beginning at 18 kg BW; G1, beginning at 27 kg BW; G2, beginning at 41 kg BW; F1, beginning at 58 kg BW; F2, beginning at 78 kg BW; and F3, beginning at 101 kg BW). The corn co-product diets contained increasing levels of the co-product; from 5 to 30% over the course of six feeding phases. Co-products used included distillers dried grains with solubles (DDGs), corn germ meal (CGM), and dehulled, degermed corn (DDC). Pigs were allocated to each chamber by weight in order to minimize body weight differences within each chamber. Barrows were provided ad libitum access to feed and water. New feed was offered daily between 06:00 and 09:00 h. Feed data were recorded daily and remaining feed was removed and weighed from the feeders at the end of each feeding phase from which average daily intake was calculated. Oxygen and carbon dioxide monitoring of the chambers occurred in a sequential manner, beginning first with incoming air, then sampling exhaust air from each of the eight chambers. Airflow rates into each chamber were measured continuously, allowing for calculation of gas emission rates when flow was multiplied by concentration. Pigs offered the DDGs diet consumed more oxygen and produced more carbon dioxide than pigs fed the remaining treatments. Apparent digestibility of energy was greater, across all feeding phases, in pigs offered the DDC diets. However; observed differences in energy utilization measures did not translate to performance differences.

Introduction

Corn co-products are of increasing importance in swine diets. However; how much can be incorporated is still up for debate. Recent work suggests that higher amounts can be included in swine diets if pigs are slowly adapted to the co-products. While much of the current focus is on the feeding of distillers grains, evaluation of additional co-products is needed as well. In particular is the need to determine the energy utilization of corn co-products and diets containing these co-products.

Objectives

1. Quantify gross energy consumed and gross energy of feces and urine excreted from finishing pigs fed diets containing corn and soybean meal or corn co-products (dehulled, degermed corn, DDC; corn germ meal, CGM; or distillers dried grains with solubles, DDGS) and soybean meal diets when housed in metabolism crates.
2. Determine heat production of grow-finish swine fed these same diets when group housed in indirect calorimeters (six pigs per calorimeter and data expressed as g O_2 consumed per g gross energy consumed).
3. Pool the data from the two studies to establish a net energy assessment of each diet and share this data with colleagues pursuing the development of an alternate net energy system and/or evaluation of the current net energy system.

Materials & Methods

This project was conducted as an add-on study to NPB 05-111 "Influence of corn co-products on air emissions and nutrient excretions from grow-finish swine". Four diets were fed to growing swine in order to compare corn (C) to corn co-products and the impact on swine performance and air emissions (Tables 1 and 2). The corn co-product diets contained increasing levels of the co-product; from 5 to 30% over the course of six feeding phases. Co-products used included distillers dried grains with solubles (DDGs), corn germ meal (CGM), and dehulled, degermed corn (DDC). Crossbred barrows (six per chamber at the start of the project; initial BW = 20.1 kg) were housed in eight indirect calorimeters. Pigs were allocated to each chamber by weight in order to minimize body weight differences within each chamber. The pigs were penned in a 3.05 m × 1.52 m raised deck with Tenderfoot® flooring. Swinging nipple waters were located above the middle of the pen and a two-hole Smidley feeder (Marting Manufacturing, Britt, IA) was located at one end of each pen. Chamber temperatures (18.3°C to 25.6°C) were adjusted weekly based on the average body weight within the chamber so as to remain in the thermoneutral zone of the animal. Fluorescent lighting was programmed to come on at 07:00 h and go off at 18:00 h.

Six feeding phases followed: Starter Phase (S1; beginning at 18 kg BW), Grower Phase 1 (G1; 27 kg BW), Grower Phase 2 (G2; 41 kg BW), Finisher Phase 1 (F1; 58 kg BW), Finisher Phase 2 (F2; 78 kg BW) and Finisher Phase 3 (F3; 101 kg BW). Pigs were offered one of mash diets during each phase: a control corn diet (C), a diet with increasing amounts of dehulled, degermed corn (DDC), a diet with increasing amounts of dried distillers grains with solubles (DDGs) and a diet with increasing amounts of corn germ meal (CGM). Co-product content increased from 0% to 30% as pigs progressed through the feeding phases. Tables 1 and 2 illustrate the formulated diet composition and analyzed CP, lysine, and energy contents that were present in each diet. Diets were formulated to contain similar lysine and energy content. Each diet was offered in two of the eight chambers during the six feeding periods and pigs in each chamber were fed the same treatment throughout the study.

Barrows were provided ad libitum access to feed and water. New feed was offered daily between 06:00 and 09:00 h. Feed data were recorded daily and remaining feed was removed and weighed from the feeders at the end of each feeding phase from which average daily intake was calculated. Diets were assigned, randomly, to groups in each of the eight chambers at the start of each feeding phase. Diets were sampled weekly and pooled together at the end of the feeding phase for proximate and amino acid analyses. At the end of F1, one pig was removed from each chamber such that five pigs remained in each pen for the remaining finisher phases (F2 and F3).

Through software (LabVIEW Ver. 7.0, National Instruments; Austin, TX) control oxygen and carbon dioxide monitoring of the chambers occurred in a sequential manner, beginning first with incoming air, then sampling exhaust air from each of the eight chambers. The incoming air line was allowed to purge for 14.5 min before the start of data collection. Following purging, data was collected for 5.5 min. Both gases were measured simultaneously within a sample stream. Samples from the chambers were pulled to a sampling manifold using a Cole-Parmer vacuum pump (Cole-Parmer Instrument Company, Vernon Hills, IL) at a rate of 30 L/min, through Teflon tubing (5 m long with an outer diameter of 0.95 cm) placed 5 cm into the exhaust line of each chamber. From the manifold the air stream was diverted into a BINOS Model 100/2 (Rosemont Analytical). Airflow rates into each chamber was measured continuously, allowing for calculation of gas emission rates.

Gas concentrations were recorded every 30 sec during the last 5.5 min of sampling in each chamber. The recorded values were exported to a spreadsheet, adjusted to standard temperature and pressure, and averaged. All averaged incoming air gas concentrations were subtracted from the chamber gas concentrations before chamber averages were calculated. Averages were calculated to determine the emissions during the 2 h and 20 m time that it took to sample a chamber again.

Twice weekly fecal and urine samples were collected from each pig and pooled, by weight, to provide a chamber sample. The assumption was made that each individual sample was representative of the day and each pig within a pen excreted a similar mass of urine and feces. Feed samples were collected for each diet weekly and pooled by feeding phase. Diet, urine, and fecal samples were analyzed for energy content using a bomb calorimeter. All samples were analyzed in triplicate.

Results

Feeding the corn co-product diets did not alter animal performance compared to corn diets when co-products were fed at increasing amounts over the life-cycle (table 3). Apparent digestibility of energy was greater in pigs offered the DDC diet than the remaining diets, which did not differ from each other. Apparent digestibility of energy increased as pigs aged and there were no interactions of dietary treatment and feeding phase. The increased apparent digestibility of energy in the pigs offered the DDC diet did not translate to better growth (table 3), suggesting that while there was statistical significance, either another nutrient was limiting for improved growth or the numerical difference was insufficient to result in performance differences.

Tables 4 and 5 depict oxygen consumption and carbon dioxide production associated with each diet. Oxygen consumption was greater in pig groups offered the DDGs diets with no differences observed between the other three diets (table 4). Phase effects were observed with decreasing oxygen consumption observed (mg per kJ of energy consumed) with increasing age of the pigs. A treatment by feeding phase interaction was observed (data not shown); however the effect was inconsistent across treatments and phases and therefore difficult to explain and support. Consistent with the greater oxygen consumption, carbon dioxide production was greater in pig groups offered the DDGs diet than the other three treatment diets. In spite of greater heat production (oxygen consumption) by pigs in this group, when fed a diet containing similar energy content as the remaining treatments, no feed intake or growth differences were observed.

Data will be made available to colleagues initially by posting this report on the National Pork Board website. More detailed data will be made available upon request or as part of the scientific publication process.

Discussion

Diets were formulated to contain similar energy contents thereby allowing determination of whether or not energy in diets containing corn co-products could be used as efficiently as energy contained in a corn-only diet. The combination of performance data, energy digestibility data, and gas data collected within this study suggest that increasing amounts of corn co-products can be fed to swine as feeding phases progress without deleterious effects on performance. However; carcass evaluations were not conducted as part of this study and may be the limiting factor for including corn co-products at levels as high as were fed in this study (30% in the final finishing diet).

Room temperatures were maintained across rooms so the greater heat production in rooms where the DDGs diets were fed may have been compensated for by increased airflow and/or air conditioning in those rooms. While flow rates were recorded, without energy load information, it is not possible to know if more energy was needed in terms of thermal environment control in order to result in similar performance. A more rigorous study, considering the feed ingredients under basal metabolic conditions and as ingredients rather than as a complete diet would be necessary to make further conclusions.

Table 1. Composition of dietary treatments during starter and grower swine feeding phases [a].

Item	*Starter phase 1*				*Grower phase 1*				*Grower phase 2*			
	C[b]	DDGs	DDC	CGM	C	DDGs	DDC	CGM	C	DDGs	DDC	CGM
Ingredient, % (as-fed basis)												
Corn	55.50	51.00		52.71	69.50	60.85		61.14	74.74	62.00		66.00
DDGs		5.00				10.00				15.00		
DDC			53.50				67.17				72.40	
CGM				5.00				10.00				15.00
Soybean meal	33.80	33.41	35.79	33.56	26.17	25.00	28.50	24.65	21.20	19.19	23.55	15.15
Whey, dried	5.00	5.00	5.00	3.00								
Vegetable oil	1.60	1.60	1.60	1.60	0.30	0.30	0.30	0.20	0.30	0.30	0.30	
Dicalcium phosphate	1.59	1.40	1.60	1.58	1.38	1.04	1.42	1.34	1.10	0.59	1.13	1.05
Limestone	0.80	0.88	0.80	0.84	0.89	1.05	0.85	0.91	0.90	1.16	0.86	0.95
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin mix	0.30	0.30	0.30	0.30	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral mix	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
L-Lysine/HCl					0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.20
Celite[c]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Analyzed composition (dry matter basis)												
Crude protein, %	22.51	23.91	21.33	23.48	19.77	21.14	19.46	21.03	16.98	19.25	17.90	17.46
Lysine, %	1.35	1.38	1.36	1.41	1.21	1.27	1.14	1.26	1.08	1.13	0.94	1.07
Sulfur, %	0.16	0.18	0.16	0.16	0.14	0.19	0.16	0.16	0.13	0.19	0.14	0.14

[a]Starter phase 1: duration = 14 d, average initial BW = 18 kg; Grower phase 1: duration = 21 d, average initial BW = 27 kg; Grower phase 2: duration = 21 d, average initial BW = 41 kg.
[b]C – corn control diet; DDGs – dried distillers grain with solubles diet; DDC – dehulled, degermed corn diet; CGM – corn germ meal diet.
[c]Celite – indigestible marker (World Minerals Corp; Lompoc, CA).

Table 2. Composition of dietary treatments during swine finisher feeding phases [a].

Item	*Finisher phase 1*				*Finisher phase 2*				*Finisher phase 3*			
	C[b]	DDGs	DDC	CGM	C	DDGs	DDC	CGM	C	DDGs	DDC	CGM
Ingredient, % (as-fed basis)of complete diet												
Corn	79.15	59.50		65.98	82.19	60.07		60.90	86.20	58.65		60.91
DDGs		20.00				25.00				30.00		
DDC			76.64				79.70				83.66	
CGM				20.00				25.00				30.00
Soybean meal	17.00	17.17	19.50	10.37	13.40	12.00	15.88	10.80	9.76	8.50	12.30	6.00
Whey, dried												
Vegetable oil	0.30	0.20	0.30		1.00		1.00		0.80		0.80	
Dicalcium phosphate	0.90	0.22	0.95	0.85	0.76		0.79	0.65	0.59		0.62	0.43
Limestone	0.90	1.25	0.86	0.97	0.90	1.28	0.88	1.00	0.90	1.20	0.87	1.01
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin/trace	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral mix	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
L-Lysine/HCl	0.10		0.10	0.18	0.10		0.10		0.10		0.10	
Celite[c]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Analyzed composition (dry matter basis)												
Crude protein, %	16.20	19.62	15.88	16.24	14.65	18.29	14.29	16.46	11.90	18.35	12.93	15.32
Lysine, %	0.89	1.02	0.84	0.93	0.81	0.88	0.73	0.83	0.70	0.77	0.66	0.68
Sulfur, %	0.12	0.20	0.12	0.13	0.11	0.11	0.11	0.15	0.10	0.21	0.11	0.13

[a]Finisher phase 1: duration = 21 d, average initial bodyweight = 58 kg; Finisher phase 2: duration = 21 d, average initial bodyweight = 78 kg; Finisher phase 3: duration = 14 d, average initial bodyweight = 101 kg.

[b]C – corn control diet; DDGs – dried distillers grain with solubles diet; DDC – dehulled, degermed corn diet; CGM – corn germ meal diet.

[c]Celite – indigestible marker (World Minerals Corp; Lompoc, CA).

Table 3. Pen performance and apparent digestibility of energy, over 6 feeding phases, for pigs fed 4 dietary treatments.

Dietary treatment[a]	*Feeding phase*[b]	*Phase weight gain, kg*[c]	*Phase feed consumption, kg*	*G:F*	*Apparent digestibility of energy*
C	S1	43.2	88.6	0.49	-5.77
	G1	77.0	213.0	0.36	26.34
	G2	113.0	278.3	0.41	41.59
	F1	58.0	304.2	0.20	48.50
	F2	94.5	300.4	0.31	49.38
	F3	64.8	228.2	0.29	51.89
DDGs	S1	35.9	82.0	0.44	-12.47
	G1	106.6	204.9	0.52	24.95
	G2	121.6	270.2	0.45	38.33
	F1	43.6	300.2	0.18	46.37
	F2	95.5	296.2	0.32	44.40
	F3	49.5	234.9	0.21	52.37
DDC	S1	42.3	83.2	0.51	2.53
	G1	94.5	211.8	0.45	34.12
	G2	122.3	295.6	0.41	50.50
	F1	42.5	349.7	0.19	63.76
	F2	94.8	345.4	0.27	64.27
	F3	67.3	234.4	0.29	63.03
CGM	S1	44.1	87.8	0.51	-6.23
	G1	79.3	187.5	0.42	21.17
	G2	111.1	256.5	0.44	34.39
	F1	51.6	300.9	0.17	44.65
	F2	88.9	300.4	0.30	44.00
	F3	55.0	235.1	0.24	49.93
[d]SEM		12.21	31.66	0.06	5.01
Cumulative over all phases					
C		468.4	1412.6	0.33	35.32[b]
DDGs		440.7	1388.2	0.32	32.32[b]
DDC		464.5	1519.8	0.31	46.37[a]
CGM		436.1	1360.5	0.33	31.32[b]
Source of variation					
Diet		0.52	0.06	0.98	<0.01
Phase		<0.01	<0.01	<0.01	<0.01
Diet × Phase		0.67	0.86	0.83	0.99

[a]C - corn control diet; DDGs – dried distillers grain with solubles diet; DDC – dehulled, degermed corn diet; CGM – corn germ meal diet.

[b]Starter phase 1: duration = 14 d, average initial BW = 18 kg; Grower phase 1: duration = 21 d, average initial BW = 27 kg; Grower phase 2: duration = 21 d, average initial BW = 41 kg, Finisher phase 1: duration = 21 d, average initial bodyweight = 58 kg; Finisher phase 2: duration = 21 d, average initial bodyweight = 78 kg; Finisher phase 3: duration = 14 d, average initial bodyweight = 101 kg.

[c]6 pigs per pen in S through F1 phases, 5 pigs per pen in F2 and F3 phases; 1 pen per chamber; 2-3 chambers per treatment.

[d]SEM - standard error of the mean.

Table 4. Least squares means of oxygen emission (consumption) from swine fed diets containing corn or corn co-products during the starter and grower phases.

	Average daily concentration,%	*Average daily emission rate, mg min^{-1}*	*Cumulative average daily emission mass, g d^{-1}*	*Daily emissions, mg kg^{-1} BW*	*Daily emissions, mg kJ^{-1} energy consumed*
Main effect means					
Diet[a]					
C	20.53[c]	-6,594 [a]	-9,212 [a]	-32,043 [b c]	-42.85 [a]
DDGs	20.53 [c]	-7,280 [b]	-10,150 [b]	-32,361 [c]	-45.97 [b]
DDC	20.52 [b]	-6,510 [a]	-9,117 [a]	-29,552 [b]	-40.54 [a]
CGM	20.51 [a]	-6,483 [a]	-9,012 [a]	-29,519 [a]	-41.57 [a]
Phase[b]					
Starter phase 1	20.52	-4,386	-6,247	-43,158	-51.97
Grower phase 1	20.55	-5,777	-8,147	-38,527	-45.85
Grower phase 1	20.44	-7,658	-10,860	-35,715	-44.72
Finisher phase 1	20.49	-9,101	-12,410	-30,718	-46.35
Finisher phase 2	20.55	-6,015	-8,577	-18,637	-32.06
Finisher phase 3	20.57	-7,363	-99,912	-18,456	-35.42
Source of variation					
Diet	<0.01	<0.01	<0.01	<0.01	<0.01
Phase	<0.01	<0.01	<0.01	<0.01	<0.01
Diet × Phase	<0.01	<0.01	<0.01	<0.01	<0.01

[a] C – corn control diet; DDGs – dried distillers grain with solubles diet; DDC – dehulled, degermed corn diet; CGM – corn germ meal diet.

[b] Feeding phases: Starter phase 1: duration = 14 d, average initial BW = 18 kg; Grower phase 1: duration = 21 d, average initial BW = 27 kg; Grower phase 2: duration = 21 d, average initial BW = 41 kg.

Table 5. Least squares means of carbon dioxide emissions from swine fed diets containing corn or corn co-products during the starter and grower phases.

	Average daily concentration, ppm	*Average daily emission rate, mg min^{-1}*	*Cumulative average daily emission mass, g d^{-1}*	*Daily emissions, mg kg^{-1} BW*	*Daily emissions, mg g^{-1} energy consumed*
Main effect means					
Diet[a]					
C	759[a]	5,222[b]	7,284[a b]	24,075[b]	32.97[a]
DDGs	764[a]	5,638[c]	7,875[c]	24,287[b]	34.73[b]
DDC	836[b]	5,401[b]	7,547[b]	23,612[b]	32.61[a]
CGM	858[c]	5,014[a]	6,991[a]	22,523[a]	32.04[a]
Phase[b]					
Starter phase 1	847	2,701	3,839	26,683	32.36
Grower phase 1	822	4,285	6,020	28,586	33.91
Grower phase 1	755	6,683	9,440	31,024	39.35
Finisher phase 1	781	7,452	10,267	25,322	38.32
Finisher phase 2	739	5,408	7,723	16,740	28.91
Finisher phase 3	883	5,383	7,257	13,391	25.67
Source of variation					
Diet	<0.01	<0.01	<0.01	<0.01	<0.01
Phase	<0.01	<0.01	<0.01	<0.01	<0.01
Diet × Phase	<0.01	<0.01	<0.01	<0.01	<0.01

[a] C – corn control diet; DDGs – dried distillers grain with solubles diet; DDC – dehulled, degermed corn diet; CGM – corn germ meal diet.

[b] Feeding phases: Starter phase 1: duration = 14 d, average initial BW = 18 kg; Grower phase 1: duration = 21 d, average initial BW = 27 kg; Grower phase 2: duration = 21 d, average initial BW = 41 kg.