ENERGY AND NUTRIENT DIGESTIBILITY OF CORN DISTILLERS CO-PRODUCTS FED TO GROWING AND FINISHING PIGS

BY

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ABSTRACT

Two experiments were conducted to measure DE, ME, NE apparent ileal digestibility (AID), and apparent total tract digestibility (ATTD) of energy and nutrients in distillers dried grains with solubles (DDGS) and in high protein distillers dried grains (HP-DDG) fed to growing and finishing pigs. One source of conventional DDGS (DDGS-CV), 1 source of uncooked DDGS (DDGS-BPX), and 1 source of HP-DDG were used. In Exp. 1, a total of 52 growing pigs (initial BW: 20.8 ± 2.06 kg BW) and 52 finishing pigs (initial BW: 87.2 ± 9.77 kg BW) were used. Within each stage of growth, 16 pigs were randomly selected as the initial slaughter group. The remaining pigs within each stage of growth were randomly allotted to 4 treatment groups of 9 pigs that were harvested at the conclusion of the experiment. Treatments included a basal diet containing corn and soybean meal and 3 diets that were formulated by mixing 70% of the basal diet and 30% of DDGS-CV, DDGS-BPX, or HP-DDG. Results showed that in growing pigs, the NE of DDGS-BPX (1,596 kcal/kg), DDGS-CV (1,665 kcal/kg), and HP-DDG (1,783 kcal/kg) were not different. In finishing pigs, the NE of DDGS-CV (2,718 kcal/kg) was greater ($P < 0.05$) than the NE of DDGS-BPX (2,065 kcal/kg), but the NE of HP-DDG (2,291 kcal/kg) was not different from the NE of DDGS-CV or DDGS-BPX. The NE of ingredients was not different for growing and finishing. In Exp. 2, sixteen growing pigs (initial BW: 24.3 ± 3.41 kg BW) and 16 finishing pigs (initial BW: 91.9 ± 20.2 kg BW) were fitted with a T-cannula in the distal ileum and allotted to the same 4 dietary treatment groups as in Exp. 1. Results showed that in growing pigs, the ME of HP-DDG (4,024 kcal/kg of DM) was greater ($P < 0.05$) than the ME of DDGS-BPX (3,740 kcal/kg of DM), but the ME of DDGS-CV (3,935 kcal/kg of DM) was not different from the ME of HP-DDG or DDGS-BPX. In finishing pigs, the ME did not differ among ingredients

(3,882, 3864, and 4,045 kcal kg of DM for DDGS-BPX, DDGS-CV, and HP-DDG, respectively). At both stages of growth, the AID of nutrients was not different among ingredients. The ATTD of CP, OM, and carbohydrates was, greater ($P < 0.05$) in HP-DDG than in DDGS-BPX or DDGS-CV, but the ATTD of acid hydrolyzed ether extract was greater ($P < 0.05$) in DDGS-BPX and DDGS-CV than in HP-DDG. In conclusion, the NE of DDGS-CV, DDGS-BPX, and HP-DDG is not affected by the stage of growth, but no consistent differences among the 3 feed ingredients were observed.

Key words: Distillers dried grains with solubles, high-protein distillers dried grains, NE, ME, pigs

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LIST OF ABBREVIATIONS

AA	Amino acid (s)
ADF	Acid detergent fiber
ADFI	Average daily feed intake
ADG	Average daily gain
AID	Apparent ileal digestibility
AOAC	Association of Analytical Chemist
ATTD	Apparent total tract digestibility
Arg	Arginine
B	Blood weight
BW	Body weight
ºC	Degrees Celsius
CER	Calculated energy retention
CCW	Chilled carcass weight
CHO	Total carbohydrates
CP	Crude protein
Cys	Cysteine
d	day
DE	Digestible energy
DP	Dressing percentage
DDGS	Distillers dried grains with solubles
DM	Dry matter
EE	Ether extract
FHP	Fasting heat production
GE	Gross energy

G:F	gain to feed ratio
h	Hours
H	Heart weight
HCW	Hot carcass weight
HI	Heat increment
His	Histidine
HP-DDG	High protein distillers dried grains
Ile	Isoleucine
ISG	Initial slaughter group
ISGi	Energy and nutrient concentration of pigs in initial slaughter group
INRA	Institut National de la Recherche Agronomique, Saint-Gilles, Fr
IU	International units
Kcal	Kilocalories
Kg	Kilograms
Leu	Leucine
LW	Live weight
Lys	Lysine
Mcal	Megacalories
ME	Metabolizable energy
MER	Measured energy retention
Met	Methionine
MLW	Mean metabolic body weight
NDF	Neutral detergent fiber
NE	Net energy
NRC	National Research Council

O	Organ weight
OM	Organic matter
Phe	Phenylalanine
SEM	Standard error of the mean
TDF	Total dietary fiber
Thr	Threonine
TW	Total weight
Trp	Tryptophan
U.S.	United States of America
Val	Valine
VFA	Volatile fatty acids
Wt	Weight

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CHAPTER 1

INTRODUCTION

Energy is the most costly component in swine diets (Noblet et al., 1993) and accurate determination of energy values of feed ingredients is important. To describe the utilization of energy in pigs, DE, ME, and NE systems have been developed. Although the NE system predicts more accurately the true energy value of a feed ingredient in pigs (Noblet et al., 1994), the DE or ME systems are more frequently used in the U.S.

Typically, these corn distillers co-products contain a higher concentration of fiber than corn (Pedersen et al., 2007), and the fiber concentration may vary depending on the source and type of corn distillers co-product (Shurson and Alghamdi, 2008). The ATTD of GE is negatively associated with the concentration of fiber in a feedstuff (Noblet and Le Goff, 2001), and the ATTD of GE in corn distillers co-products is, therefore, usually lower than in corn (Stein and Shurson, 2009). An increase in the ATTD of GE with BW is often observed (Noblet and Le Goff, 2001), which is associated with improved digestive utilization of fiber (Noblet, 2007). In theory the NE of corn distillers co-products should, therefore, increase as pigs become older, but this has not been experimentally verified.

The NE system is believed to more accurately predict the energy value of high fiber feedstuffs than DE and ME systems (Payne and Zijlstra, 2007) because it accounts for the lower efficiency of utilization of ME originating from hingut fermentation than for enzymatically degraded carbohydrates (Noblet et al., 1994). It is, therefore, believed that the NE system will more accurately predict the energy value of corn distillers co-products, but the NE values of distillers co-products have not yet been measured.

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CHAPTER 2

LITERATURE REVIEW

INTRODUCTION

Production of ethanol for fuel will impact the formulation of diets for pigs, because most of the distillers co-products that are used in the U.S. are derived from fermentation of corn for fuel ethanol production (Urriola et al., 2009). About 30 % of the dry weight of the corn grain used in ethanol distillation will become corn distiller co-products (Hayes, 2008). During the last decade, more than 100 new ethanol distillation plants have been built in the Midwestern region of the U.S. It is estimated that more than 7.9 billion gallons of ethanol were produced in 2008 in the U.S., and this may increase to 16.8 billion gallons by 2013 (Hayes, 2008). As a result, the production of distillers dried grains with solubles (**DDGS**) will increase from 9.3 million metric tons in 2007 to 36 million tons in 2010 (Fox, 2008). With the expansion of the fuel industry, many companies have developed more efficient fermentations processes based on different technologies, which results in a number of different sources of corn distillers co-products. Fox (2008) estimated that of the total production of corn distillers co-products in 2007, 36% were marketed wet and 64% were marketed as DDGS.

CORN DISTILLERS CO-PRODUCTS

Conventional distillers dried grains with solubles (**DDGS-CV**) is the most common corn distillers co-product used in livestock diets in the U.S. Conventional DDGS is produced after fermentation of ground corn grain in a procedure that requires input of external heat and cooking of the corn to gelatinize the starch. After heating, the product is cooled and enzymes are added to facilitate fermentation by yeast using the starch to produce ethanol. The final composition of DDGS-CV is a product containing distillers grains and at least 70% of the condensed solubles that are produced after fermentation (Stein, 2008).

Distillers dried grains with solubles may also be produced using the BPX technology, which is a new technology that uses enzymes to predigest the starch prior to yeast fermentation. The DDGS that is produced using this technology is called DDGS-BPX.

High protein distillers dried grains (**HP-DDG**) is produced after the fermentation of corn grain that has been de-hulled and de-germed prior to fermentation. The resulting distillers dried grains are not mixed with the condensed solubles. As a result of the de-hulling and de-germing, HP-DDG has a lower concentration of fat, fiber, and P, but a greater concentration of CP (Stein, 2008).

The concentration of nutrients in corn distillers co-products vary among sources and within plants over time (Shurson and Alghamdi, 2008). Factors that may affect the nutrient composition of corn distillers co-products include: i) origin of the raw materials: type of grain, grain variety, and grain quality, and ii) processing factors: grinding procedure, cooking, dilution of converted grains, fermentation, distillation, and amount of solubles mixed with the distilled grains.

Concentration of Energy in Corn Distillers Co-Products

The average GE of several sources of DDGS and HP-DDG is approximately 5,434, and 5,399 kcal/kg of DM respectively, and these values are greater than the GE in corn (Pedersen et al., 2007; Widmer et al., 2007). However, Stein (2008) reported that the ATTD of GE is lower for conventional DDGS (76.8%) than for HP-DDG (88.2%) and corn (90.4%), because the fiber concentration in DDGS is greater than in corn and HP-DDG (Stein and Shurson, 2009). As a consequence, DE and ME in DDGS (4,140 and 3,897 kcal/kg of DM, respectively) are similar to the DE and ME in corn (4,088 and 3,989 kcal/kg of DM, respectively), but DE and ME in HP-DDG (4,763 and 4,476 kcal/kg of DM, respectively) are greater than in DDGS and corn (Pedersen et al., 2007; Widmer et al., 2007). Values for DE and ME in DDGS have also been published by NRC (1998), Spiehs et al. (2002), and Stein et al. (2009), but values for NE in DDGS and HP-DDG have not been measured.

ENERGY SYSTEMS

The principles for use of NE systems are based on techniques used for measurements of energy metabolism and feeding value in the early 1900's. The work of Kellner in Germany and Armsby in the U.S. led to the development of the NE system to describe feed energy utilization in ruminants at the beginning of the 20^{th} century (Baldwin, 1995). Although NE systems are used in several European countries, energy in feed ingredients is usually expressed as DE or ME in North America.

Gross energy intake is the total amount of energy consumed by an animal, and it represents the maximum amount of energy that is available for use by the animal (Ewan, 2001). The concentration of GE in a feed ingredient is usually expressed as kilocalories per gram, and depends on the concentration of carbohydrates, lipids, proteins and minerals in the ingredient. The heat released after combustion of 1 g of carbohydrates, lipids, or protein is 4.2, and 5.6 kcal/g, respectively (Ewan, 2001). Gross energy is usually measured using bomb calorimetry.

After ingestion, only a part of the GE will be absorbed, and the remaining portion is excreted in the feces. The amount of GE that was absorbed from the gastrointestinal tract and is available for utilization by the pig is called DE, and is calculated by subtracting the total energy in feces from the GE.

The ME concentration of a feed ingredient is calculated by subtracting urine and gaseous energy from DE (Ewan, 2001). Gaseous energy represents the energy in the methane produced by the animal, but in most cases, the loss of energy in gas is ignored when ME is calculated, because it is negligible and difficult to measure (Chiba, 2000). The ME is, therefore, a measure of the amount of energy that is available for metabolic processes in the pig (Just, 1982b).

Metabolizable energy can be lost as heat or recovered as body tissue energy or lactation energy. The energy lost as heat or recovered in body tissue is commonly referred to as heat increment and retained energy, respectively. This division requires either the measurement of heat loss or retained energy.

By definition, the NE is the difference between ME and heat increment. The NE can be used for maintenance (**NE_m**) of the animal or it can be used for production (**NE_p**). Net energy for maintenance is energy that is used to maintain the physiological functions of the animal, e.g., to keep the animal alive and maintain a constant body temperature. The NE_p represents the NE supplied in excess of the NE_m and is used for growth or milk production (Baldwin, 1995).

Heat Increment

The heat increment is the increase in heat production following consumption of feed when the animal is in a thermoneutral environment (Baldwin, 1995). Heat increment may also be called the calorigenic effect, the thermogenic action, or the specific dynamic effect or specific dynamic action. Brody (1945) described the components of heat increment as the heat produced from the work associated with physical and chemical processes involved in mastication, digestion, absorption, and metabolism of ingested food. Baldwin (1995) divided the heat increment into 2 portions: i) the heat needed for digestion and assimilation of feed for maintenance, called the heat increment of maintenance and ii) the heat increment associated with maintaining a constant body temperature and with product synthesis.

The Concept of Maintenance

The maintenance requirement represents the ME intake required to maintain an energy balance of zero, when the animal is not thermo regulating (Baldwin, 1995). The ME_m is the point where ME intake equals the sum of fasting heat production (**FHP**) and the heat increment for maintenance, and the animal is not gaining or losing weight. The total NE_m, is equal to the heat production at zero feed intake, which is also called FHP.

The “surface law” is used to express the maintenance requirement. Heat loss is believed to be proportional to the surface area of the animal. Therefore, heat production is also proportional to the surface area because heat loss equals heat production (Brody, 1945). The allometric relationship between FHP and surface area can be described as:

$$FHP = aBW^b$$

where, FHP is a function of body weight (**BW**). The b exponent varies when determined in animals of different sex, age, and species (Brody, 1945). Baldwin (1995) summarized several maintenance functions that comprise the FHP: kidney work (Na^+ transport), heart work, nervous functions, respiration, protein resynthesis, triacylglycerol resynthesis, and Na^+ (membrane potential).

To determine the maintenance energy requirements in pigs, measurements of heat production can be obtained either directly or indirectly using calorimeters. Another approach is to estimate energy retention by comparing the total energy content of groups of animals before and after an experimental period using comparative slaughter (Just et al., 1982a and b).

When the comparative slaughter method is used, the linear regression of energy retention from pigs fed increasing levels of energy is extrapolated to the point of zero energy used for maintenance (practical NE_m), while the theoretical NE_m can be determined by measuring the fasting energy loss (de Lange and Birkett, 2005). The NE is usually calculated as the sum of FHP and retained energy (Noblet et al. 1994). When values for indirect calorimetry and comparative slaughter are compared it should be considered that animals are restrained in environmentally controlled respiration chambers, limiting activity, social interaction, and temperature regulation. As a consequence, energy retention tends to be lower if measured using comparative slaughter procedures compared with indirect calorimetry (Reynolds, 2000). The major environmental factors that influence heat production are temperature and physical activity of the animal (NRC, 1998). Therefore, when the temperature is below the thermoneutral zone of the pig, the animal will expend more energy to maintain body temperature and a decrease in environmental temperature below the critical temperature results in an increase in heat production (Noblet et al., 1985).

CONCLUSION

Distillers co-products will be used in swine diets in the future because the growth of the ethanol and biopolymers industry has resulted in a sharp increase in the amount of corn distillers co-products that are produced; however, the NE concentration in DDGS and HP-DDG has not yet been measured. The NE system is believed to be more accurate to express the energy value of a feedstuff than the DE and ME systems, because DE and ME systems tend to overestimate the energy value of protein - and fiber- rich feedstuffs and underestimate the energy value of fat (Noblet et al., 1994). To more accurately express the energy value of DDGS and HP-DDG, it is, therefore, necessary to measure their NE content.

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CHAPTER 3

NET ENERGY OF DISTILLERS DRIED GRAINS WITH SOLUBLES AND HIGH PROTEIN DISTILLERS DRIED GRAINS FED TO GROWING AND FINISHING PIGS

ABSTRACT

An experiment was conducted to measure the NE of distillers dried grains with solubles (DDGS) and in high protein distillers dried grains (HP-DDG) fed to growing and finishing pigs. One source of conventional DDGS (DDGS-CV), 1 source of uncooked DDGS (DDGS-BPX), and 1 source of HP-DDG were compared. A total of 52 growing pigs (initial BW: 20.8 ± 2.06 kg BW) and 52 finishing pigs (initial BW: 87.2 ± 9.77 kg BW) were used. Within each stage of growth, 16 pigs were randomly selected as the initial slaughter group, and these pigs were harvested at the initiation of the experiment. The remaining pigs within each stage of growth were randomly allotted to 4 treatment groups of 9 pigs based on BW. Pigs were housed individually and had free access to feed and water. Treatments included a basal diet containing mainly corn and soybean meal and 3 diets that were formulated by mixing 70% of the basal diet and 30% DDGS-CV, DDGS-BPX, or HP-DDG. Experimental diets were fed to growing pigs for 28 d and to finishing pigs for 35 d. All pigs were harvested at the end of the experiment, and carcass, blood, and viscera were collected and analyzed for CP, ether extract, and GE. The NE for DDGS-CV, DDGS-BPX, and HP-DDG were calculated by subtracting the contribution of NE from the basal diet to the NE of the treatment diets. Results showed that for both growing and finishing pigs, growth performance was not affected by dietary treatments. In growing pigs, no differences among treatment groups were observed for energy retention and the NE of

DDGS-BPX (1,596 kcal/kg), DDGS-CV (1,665 kcal/kg), and HP-DDG (1,783 kcal/kg) were not different. Finishing pigs fed the DDGS-CV diet had greater (P < 0.05) lipid gain than pigs fed any of the other diets. The NE of DDGS-CV (2,718 kcal/kg) was also greater (P < 0.05) than the NE of DDGS-BPX (2,065 kcal/kg) but the NE of HP-DDG (2,291 kcal/kg) was not different from the NE of DDGS-CV or DDGS-BPX. No interactions were observed between ingredient and stage of growth, but the NE of DDGS-CV, DDGS-BPX, and HP-DDG were not different between growing and finishing pigs. The results suggest that the NE of DDGS-CV, DDGS-BPX, and HP-DDG is not affected by the stage of growth.

Key words: Distillers dried grains with solubles, high-protein distillers dried grains, NE, pigs, stage of growth

INTRODUCTION

Distillers dried grains with solubles (**DDGS**) and high protein distillers dried grain (**HP-DDG**) may be used as a source of protein and energy in diets fed to swine (Stein and Shurson, 2009). Energy is the most expensive component of feed in swine diets (Noblet et al., 1993), and an accurate estimation of the energy value of DDGS and HP-DDG is, therefore, necessary.

In North America, energy is usually expressed as DE or ME, but DE and ME systems may overestimate the energy value of fibrous or high protein feedstuffs and underestimate ingredients that have high concentrations of fat (Noblet et al., 1994). It is, however, believed that if energy is expressed as NE rather than DE and ME, these inaccuracies may be reduced because NE systems account for the metabolic utilization of energy (Noblet et al., 1994).

Values for DE and ME of DDGS are similar to those of corn, although variability among DDGS sources has been reported (Pedersen et al. 2007, Stein et al., 2009). It has also been reported that HP-DDG contains more DE and ME than corn (Widmer et al., 2007), which is believed to be a result of the greater concentration of CP and lower fiber concentration in HP-DDG than in corn.

The NE of soybean hulls, wheat middlings, corn, soybean oil, and choice white grease were recently measured (Stewart, 2007; Kil, 2008). However, values of NE for DDGS and of HP-DDG have not been determined. The NE of corn is greater for finishing than for growing pigs because finishing pigs retain more lipids than growing pigs (de Greef et al., 1994; Kil, 2008). It is, however, not known if the NE of DDGS and HP-DDG is greater for finishing than for growing pigs. The objective of this experiment was, therefore, to measure the NE in DDGS and in HP-DDG, and to test the hypothesis that NE values for DDGS and HP-DDG are greater for finishing than for growing pigs.

MATERIALS AND METHODS

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) were obtained from the University of Illinois Swine Research Center. The average initial BW was 20.8 ± 2.06 kg and 87.2 ± 9.77 kg for the growing and finishing pigs, respectively. Within each stage of growth, pigs were randomly allotted to 6 treatment groups with 2 groups of 8 pigs and 4 groups of 9 pigs. The 2 groups with 8 pigs at each stage of growth served as the initial slaughter group and all pigs in these 2 groups were harvested at the start of the experiment. The remaining 4 treatment groups within each stage of growth were assigned to 4 dietary treatments. The experimental period was 28 d for growing pigs and 35 d for finishing pigs, and all pigs were harvested at the conclusion of the experiment.

Pigs were housed individually in 0.9 x 1.8m pens in an environmentally controlled building. Pens were equipped with a fully-slatted concrete floor, a feeder, and a bowl shaped nipple waterer. The experiment was approved by the Institutional Animal Care and Use Committee at the University of Illinois.

Dietary Treatments

Commercial sources of corn and soybean meal were used. A source of conventional DDGS (DDGS-CV) was obtained from Lincolnland Agri-Energy, LLC (Palestine, IL). A source of uncooked DDGS (DDGS-BPX) and a source of HP-DDG (Table 3.1) was obtained from Poet Nutrition (Sioux Falls, SD). The same batch of these ingredients was used for both growing and finishing pigs.

Four diets at each stage of growth were formulated (Table 3.2). The basal diet contained mainly corn and soybean meal. Chromic oxide (0.5%) was included in the diet as an indigestible marker. Vitamins and micro minerals were also included in the basal diet to exceed estimated nutrient requirements (NRC, 1998) of pigs at each stage of growth. Three additional diets were prepared by mixing 70% of the basal diet and 30% DDGS-BPX, 70% of the basal diet and 30% DDGS-CV, and 70% of the basal diet and 30% HP-DDG. All diets were provided in a meal form. Pigs were allowed ad libitum access to feed and water during the entire experimental period. Feed samples were collected weekly and pooled at the end of the experiment. A sample of each of the ingredients was collected before diets were mixed. The pooled feed and ingredient samples were stored at -20°C until analyzed.

Samples Collection and Slaughter Procedure

The BW of each pig was recorded at the initiation of the experiment and at the end of each week thereafter. Daily feed allowance was recorded for each pig and feed left in the feeders was recorded weekly on the same day the BW of pigs was recorded.

The retention of energy, protein, and lipids were estimated using the comparative slaughter procedure (de Goey and Ewan, 1975). The slaughter procedure, carcass measurements, and the chemical analyses used were similar to those described by Stewart (2007) and Kil (2008). In short, at harvest the carcass, viscera, and blood were collected from each pig and processed separately. The digestive tract was flushed with water to remove digesta, and all individual organs and the intestines were patted dry and weighed. To obtain subsamples, all carcass and viscera were ground and mixed, and all subsamples of carcass, viscera and blood were lyophilized prior to chemical analysis.

Calculations

Data for ADFI, ADG, and G:F were calculated and then 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 (kilogram) by the live BW (kilogram). The total weight of harvested pigs was calculated as follows:

$$\text{Total wt} = \text{HCW} + \text{B} + \text{V}_f + \text{O}$$

where HCW is hot carcass weight (kilogram), B is blood weight (kilogram), V_f is the weight of the full viscera (kilogram), and O is organ weight (kilogram), which includes the intestinal tract and kidneys, heart, liver, lungs, and spleen. The total digesta-free BW was calculated as follows:

$$\text{Total digesta-free BW} = \text{CCW} + \text{B} + \text{V}_e + \text{O}$$

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

For each pig, the total quantity 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 from the difference between the final quantity of energy, protein, and lipids at harvest and the initial quantity of energy, protein, and lipids. The initial body composition of the experimental pigs was determined from the body composition of pigs in the initial slaughter group (Oresanya et al., 2008). The following equation was used for this calculation:

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

where TBi is the total quantity 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, and ISGi is the average concentration (megacalories/kilogram or grams/kilogram) 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 5.66 and 9.46 kcal/g, respectively (Ewan, 2001).

The NE requirement for maintenance for each pig was calculated by multiplying the mean metabolic body weight ($kg^{0.6}$) by 128 kcal for growing pigs and 219 kcal for finishing pigs (Kil, 2008). The mean metabolic BW of each pig was calculated as the average of the metabolic BW obtained weekly during the experimental period. The NE of each diet was calculated as the sum of the energy retained in the body and the total operational NE requirement for maintenance during the experimental period (Ewan, 2001). The NE of DDGS-BPX, DDGS-CV, and HP-DDG were subsequently calculated using the difference method by subtracting the NE contribution from the basal diet to the NE of the diets containing DDGS-BPX, DDGS-CV, and HP-DDG (de Goey and Ewan, 1975).

Statistical Analyses

All data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC) with the individual pig as the experimental unit. Homogeneity of the variances was verified using the UNIVARIATE procedure of SAS. The residual versus the predicted plot procedure was used to analyze for outliers, but no data were identified as outliers. Diet was the fixed effect and outcome group was the random effect in the model. The differences among treatments were determined using ANOVA, 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 values for each ingredient were also compared between growing pigs and finishing pigs. The interaction between ingredients and stage of growth for the NE of ingredients was analyzed, but was not significant; therefore, the interaction was not included in the final model.

RESULTS

Initial BW, final BW, ADG, ADFI, and G:F for both growing pigs and finishing pigs were not affected by dietary treatments (Table 3.3). In growing pigs, the live BW that was recorded prior to slaughter was lower (P <0.05) for pigs fed the DDGS-BPX and DDGS-CV diets than for pigs fed the basal diet (Table 3.4), but live BW for pigs fed the HP-DDG diet was not different from pigs fed any of the other diets. Hot carcass weight, 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, but there were no differences between pigs fed the basal diet and pigs fed the DDGS-CV or the HP-DDG diets. Blood, full viscera, empty viscera, and organ weight were not different among treatments. The ratio of total organ weight to digesta-free BW was greater (*P* < 0.05) for pigs fed the HP-DDG diet than for pigs fed the basal diet, but pigs fed the DDGS-BPX and the DDGS-CV diets had ratios of total organ weight to digesta-free BW that were not different from pigs fed any of the other diets.

In finishing pigs, live BW, hot carcass weight, and chilled carcass weight were not affected by dietary treatments (Table 3.5). However, dressing percentage was greater (*P* < 0.05) for pigs fed the basal and DDGS-CV diets than for pigs fed the HP-DDG diet. Blood, full viscera, empty viscera, and organ weights were not different among dietary treatments, although pigs fed the HP-DDG diet tended (*P* = 0.06) to have a greater total viscera plus organ weight than pigs fed the basal, DDGS-BPX, or DDGS-CV diets. Total organ weight and the ratio of total organ weight to digesta-free BW was greater (*P* < 0.05) for pigs fed the HP-DDG diet than for pigs fed the DDGS-CV diet, but not different from pigs fed the basal diet and pigs fed the DDGS-BPX diet. The ratio of chilled carcass weight to total digesta-free BW was greater (*P* < 0.05) for pigs fed the basal and DDGS-CV diets than for pigs fed the HP-DDG diet, but not different from that of pigs fed the DDGS-BPX diet. The ratio of total viscera plus organ to digesta-free BW and the ratio of liver to digesta-free BW was greater (*P* < 0.05) for pigs fed the HP-DDG diet than for pigs fed the basal and DDGS-CV diets. No difference among treatments was observed for digesta-free BW.

In growing pigs, the concentration of protein in the digesta-free body was greater (*P* < 0.05) for pigs fed the DDGS-BPX diet than for pigs fed the HP-DDG diet, but not different from pigs fed the basal diet or the DDGS-CV diet (Table 3.6). The total amount of protein retained in the body and protein gain was greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the DDGS-CV or HP-DDG diets. No differences among dietary treatments were observed in lipid gain or in the ratio of lipid gain:protein gain. Measured energy retention (**MER**) and calculated energy retention (**CER**) were not affected by dietary treatments.

In finishing pigs, digesta-free BW, and digesta-free BW DM were not affected by dietary treatments. The concentration of lipids in the digesta-free body, concentration of energy in the digesta-free body, lipid gain, MER, and CER were greater ($P < 0.05$) for pigs fed the DDGS-CV diet than for pigs fed the DDGS-BPX diet (Table 3.7). However, the total amount of protein, total lipids, total energy, protein gain, and the ratio of lipid gain:protein gain were not affected by dietary treatments.

In growing pigs, no difference among treatment groups in NE intake, total feed intake, initial body energy, final body energy, energy retention, and total operational NE requirement for maintenance was observed (Table 3.8). The NE was 1,744 kcal/kg for the basal diet, 1,698 kcal/kg for the DDGS-BPX diet, 1,720 kcal/kg for the DDGS-CV diet, and 1,756 kcal/kg for the HP-DDG diet. These values were not different. The NE of DDGS-BPX, DDGS-CV, and HP-DDG were 1,596 kcal/kg, 1,665 kcal/kg, and 1783 kcal/kg , respectively and these values were not different.

In finishing pigs, initial body energy, final body energy and total operational NE for maintenance were not affected by dietary treatments, but energy retention was greater ($P < 0.05$) for pigs fed the DDGS-CV diet than for pigs fed the DDGS-BPX diet. No differences among dietary treatments for total NE intake and total feed intake were observed although pigs fed the basal diet tended ($P = 0.051$) to have greater total feed intake than pigs fed the DDGS-BPX, DDGS-CV, and HP-DDG diets. The NE was 2,140 kcal/kg for the basal diet, 2,129 kcal/kg for the DDGS-BPX diet, 2,299 kcal/kg for the DDGS-CV diet, and 2,171 kcal/kg for the HP-DDG diet. These values were not different. The NE of DDGS-CV, however, was greater ($P < 0.05$) than the NE of DDGS-BPX (2,718 kcal/kg vs. 2,065 kcal/kg), but the NE of HP-DDG (2,291 kcal/kg) was not different from the NE of DDGS-CV or DDGS-BPX.

The NE of all diets was greater ($P < 0.001$) for finishing pigs than for growing pigs (Table 3.9). The NE of DDGS-CV was also greater ($P < 0.001$) for finishing pigs than for growing pigs (2,647 vs. 1,665 kcal/kg), and the NE of DDGS-BPX and HP-DDG (2,109 vs. 1,593 and 2,220 vs. 1,783 kcal/kg, respectively) tended ($P = 0.16$ and 0.09, respectively) to be greater for finishing than for growing pigs. There was no interaction between ingredient and stage of growth. Therefore, the main effects of ingredient and stage of growth were calculated (Table 3.10). The NE of ingredient was greater ($P < 0.001$) for finishing pigs than for growing pigs (2,325 vs. 1,627 kcal/kg), but no differences among ingredients were observed.

DISCUSSION

The results for growth performance for growing and finishing pigs obtained in this experiment agree with previous observations showing that there is no difference in performance between pigs fed diets containing no DDGS and pigs fed diets containing 30% DDGS (Cook et al., 2005; DeDecker et al., 2005; Xu et al., 2007). A linear decrease in ADG and ADFI as the inclusion of DDGS in the diet increases has, however, also been reported (Fu et al., 2004; Whitney et al., 2006; Linneen et al., 2008). This inconsistency may be a result of different qualities of DDGS used, because AA digestibility may vary among sources of DDGS (Stein et al., 2006).

Widmer et al. (2008) observed reduced ADG and ADFI when HP-DDG replaced all the soybean meal in diets fed to growing pigs, but no effect of HP-DDG on growth performance was observed in finishing pigs.

The protein gains for growing (149.7 g/d) and finishing (146.5g/d) pigs fed the basal diet are similar to values reported by Quiniou et al. (1996), but slightly lower than the values reported by Kil et al. (2009). In both growing and finishing pigs, MER and CER values were similar, which indicate that the measured energy values are accurate.

No differences in dressing percentage were observed between growing pigs fed the basal diet and pigs fed the DDGS or HP-DDG-containing diets. This observation agrees with data from Widmer et al. (2008) who also reported that the dressing percentage of pigs fed DDGS or HP-DDG was similar to that of pigs fed a corn-soybean meal diet. However, the dressing percentage of finishing pigs fed the HP-DDG diet was lower than for pigs fed the basal or the DDGS-CV diets, mainly because of the increased viscera and organ weights. Increased intestinal mass has been previously reported when high fiber diets were fed to pigs (Kass et al., 1980). Reduced dressing percentage of growing finishing pigs was also reported by Whitney et al. (2006) when DDGS was increased from 10 to 20 or 30% of the diet.

In both growing and finishing pigs, the NE of diets for pigs fed the basal diet and pigs fed the DDGS-BPX diet, DDGS-CV diet, or the HP-DDG diet were not different. Similar values for DE and ME have previously been reported for DDGS and corn (Pedersen et al., 2007; Stein et al., 2009). Because DDGS contains more fiber than corn, lower NE in DDGS than in corn could be expected (Noblet et al., 1994). However, the lipid concentration in DDGS is also greater than in corn, which is expected to contribute to an increase in the NE of DDGS, because dietary lipids have a higher efficiency of utilization than protein and carbohydrates (Just et al., 1983; Black, 1995). As a result, the NE of the diets containing both DDGS-CV and DDGS-BPX were not different from the NE of the basal corn-soybean meal diet. The DE and ME in HP-DDG is greater than in corn (Widmer et al., 2007), but the NE of HP-DDG diet was not greater than the NE of the basal diet. The reason for this observation is the high NDF content (30.4 %) of the HP-DDG used in this study. A lower content of NDF in HP-DDG (16.4%) has been reported previously by Widmer et al. (2007). Another reason for the lack of a difference in NE between HP-DDG and the basal diet may be that the efficiency of utilization of protein is lower than that of carbohydrates and lipids. High protein ingredients, such as HP-DDG, tend to have a lower NE:DE ratio than ingredients with greater lipid concentrations.

The NE of DDGS and of HP-DDG obtained for growing pigs (1,671 kcal/kg) was similar to the NE of corn (1,643 kcal/kg) obtained by Kil (2008). The NE of DDGS and HP-DDG for growing pigs in this experiment was also similar to the NE of DDGS (1,673 kcal/kg) reported by Sauvant et al. (2004). The mean NE value of DDGS and of HP-DDG obtained for finishing pigs (2,325 kcal/kg) was lower than the NE of corn (2,607 kcal/kg) determined by Kil et al. (2008), but greater than the NE of DDGS for sows (1,935 kcal/kg) reported by Sauvant et al. (2004). The NE of DDGS-BPX (1,841 kcal/kg) and of DDGS-CV (2,146 kcal/kg) was also similar to the NE of DDGS (2,065 kcal/kg) reported by NRC (1998). The NE of DDGS-CV for finishing pigs was greater than the NE of DDGS-BPX, which is likely a result of the greater lipid concentration in DDGS-CV compared with DDGS-BPX.

In conclusion, the NE value of DDGS-BPX, DDGS-CV, and HP-DDG is not affected by the stage of growth, and the NE of DDGS for finishing pigs is greater than previously reported values for DDGS.

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Table 3.1. Analyzed composition of distillers dried grains with solubles (DDGS) and high protein distillers dried grains (HP-DDG), as fed basis (except DM).

	Ingredient[1]		
Composition	DDGS-BPX	DDGS-CV	HP-DDG
DM, %	88.83	89.79	91.94
GE, mcal/kg	4.88	5.01	5.01
CP, %	27.19	28.35	40.52
Ether extract, %	11.18	13.01	3.07
Acid ether extract[2], %	13.23	14.16	6.05
Ash, %	5.77	4.79	2.36
Total dietary fiber,%	28.77	28.48	28.06
ADF, %	7.52	9.71	10.29
NDF, %	28.38	35.12	30.37

[1]DDGS-BPX = distillers dried grains with solubles from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD); DDGS-CV = conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC., Palestine, IL); HP-DDG = high protein distillers dried grains (Poet Nutrition, Sioux Falls, SD).

[2]Acid ether extract = acid hydrolyzed ether extract.

Table 3.2. 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, %								
Ground corn	66.10	46.27	46.27	46.27	80.00	56.00	56.00	56.00
Soybean meal, 48%	28.00	19.60	19.60	19.60	16.50	11.55	11.55	11.55
DDGS-BPX	-	30.00	-	-	-	30.00	-	-
DDGS-CV	-	-	30.00	-	-	-	30.00	-
HP-DDG	-	-	-	30.00	-	-	-	30.00
Soybean oil	2.00	1.40	1.40	1.40	-	-	-	-
Limestone	1.50	1.05	1.05	1.05	1.50	1.05	1.05	1.05
Monocalcium phosphate	0.70	0.49	0.49	0.49	0.60	0.42	0.42	0.42
Cr_2O_3	0.50	0.35	0.35	0.35	0.50	0.35	0.35	0.35

Continue from table 3.2.

Vitamin-mineral premix	0.45	0.32	0.32	0.32	0.40	0.28	0.28	0.28
Salt	0.60	0.42	0.42	0.42	0.50	0.35	0.35	0.35
Tylan® Premix3	0.15	0.10	0.10	0.10	-	-	-	-
Energy and nutrients[1]								
GE, mcal/kg	3,941	4,297	4,310	4,292	3,776	3,986	4,019	4,139
ME, mcal/kg	3,380	3,391	3,391	3,607	3,294	3.330	3,330	3,547
DM, %	87.71	89.36	88.74	89.56	88.35	89.02	89.17	89.88
Ash, %	6.25	5.76	5.57	4.78	4.81	5.01	4.77	3.95
CP, %	20.38	21.44	22.05	26.00	14.39	18.80	18.49	21.92
Ether extract, %	4.01	6.52	6.87	4.05	3.00	5.50	6.62	3.04
Acid ether extract[2], %	4.90	7.85	8.10	5.47	3.66	6.84	7.38	5.19
Total dietary fiber, %	10.68	15.90	14.24	15.51	10.34	16.55	15.96	16.67
ADF, %	2.94	4.45	4.45	5.22	3.01	4.33	5.06	5.43

Continue from table 3.2.

NDF, %	8.65	26.42	15.57	13.67	10.08	15.62	23.70	18.06
Ca, %	0.80	0.62	0.62	0.57	0.75	0.59	0.59	0.53
Bioavailable P, %	0.04	0.27	0.27	0.20	0.16	0.25	0.25	0.17

[1]Tylosin phosphate. Elanco Animal Health. Indianapolis, IN.

[2]Values for ME, Ca, and bioavailable P were calculated (NRC, 1998); all other values were analyzed.

[3]Acid ether extract = acid hydrolyzed ether extract.

Table 3.3. Effects of treatments on growth performance of growing and finishing pigs[1].

	Diet[2,3]					
Items	Basal	DDGS-BPX	DDGS-CV	HP-DDG	SEM	*P*-value
Growing pigs						
Initial BW, kg	20.82	21.07	20.92	20.92	0.712	0.87
Final BW, kg	48.05	45.71	46.05	45.22	1.350	0.25
ADG, kg	0.973	0.890	0.898	0.868	0.039	0.21
ADFI, kg	1.887	1.664	1.724	1.719	0.078	0.15
G:F	0.518	0.536	0.521	0.507	0.016	0.53
Finishing pigs						
Initial BW, kg	85.33	89.94	86.93	88.25	3.429	0.30
Final BW, kg	127.17	127.06	127.25	126.56	4.192	0.99
ADG, kg	1.195	1.073	1.160	1.103	0.060	0.43
ADFI, kg	3.451	3.083	3.267	3.098	0.156	0.17
G:F	0.347	0.347	0.356	0.358	0.014	0.81

[1]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-PAL, and HP-DDG.

[2]DDGS-BPX = distillers dried grains with soluble from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD); DDGS-CV = conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC., Palestine, IL); HP-DDG = high protein distillers dried grains (Poet Nutrition, Sioux Falls, SD).

[3]Basal = basal diet; DDGS-BPX = diet containing 70% of basal diet and 30% of DDGS-BPX; DDGS-CV= diet containing 70% of basal diet and 30% of DDGS-CV; HP-DDG = diet containing 70% of basal diet and 30% of HP-DDG.

Table 3.4. Weights of carcass and body components of growing pigs[1].

	Diet[2,3]					
	Basal	DDGS-BPX	DDGS-CV	HP-DDG	SEM	*P*-value
Live wt, kg	44.8[y]	40.5[x]	41.9[xy]	42.0[xy]	1.14	0.01
Hot carcass wt, kg	35.0[y]	31.5[x]	32.8[xy]	32.8[xy]	0.99	0.01
Dressing percentage, %	78.1	77.7	78.1	78.0	0.58	0.94
Chilled carcass wt, kg	34.5[y]	31.0[x]	32.4[xy]	32.4[xy]	0.97	0.01
Blood wt, kg	2.18	2.00	2.02	1.99	0.091	0.26
Full viscera wt, kg	4.83	4.54	4.61	4.51	0.189	0.56
Full viscera wt, % of live wt	10.7	11.2	11.0	10.8	0.40	0.80
Empty viscera wt, kg	3.57	3.33	3.45	3.44	0.135	0.57
Empty viscera wt, % of live wt	7.94	8.27	8.22	8.22	0.261	0.75
Liver wt, kg	1.08	1.00	1.02	1.08	0.043	0.26
Heart wt, kg	0.21	0.20	0.21	0.20	0.008	0.34

Continue from table 3.4.

Kidney wt, kg	0.29	0.27	0.29	0.27	0.014	0.35
Lungs wt, kg	0.51	0.58	0.58	0.63	0.044	0.15
Spleen wt, kg	0.10	0.10	0.11	0.10	0.005	0.75
Total organ wt[4], kg	2.19	2.13	2.21	2.29	0.080	0.33
Total viscera + organ wt, kg	5.76	5.47	5.66	5.73	0.203	0.58
Total wt[5], kg	44.2^{y}	40.1^{x}	41.6^{xy}	41.6^{xy}	1.16	0.01
Total digesta-free BW, kg	42.5^{y}	38.5^{x}	40.1^{xy}	40.1^{xy}	1.14	0.01
Chilled carcass wt / total digesta-free BW, %	81.3	80.5	80.9	80.7	0.48	0.59
Empty viscera wt / total digesta-free BW, %	8.39	8.70	8.60	8.62	0.276	0.85
Total organ wt / total digesta-free BW, %	5.15^{x}	5.55^{xy}	5.52^{xy}	5.72^{y}	0.135	0.01
Total viscera+organ / total digesta-free BW, %	13.5	14.2	14.1	14.3	0.37	0.32
Liver / total digesta-free BW, %	2.53	2.61	2.55	2.71	0.083	0.32
Liver / total organ wt, %	49.0	46.9	46.3	47.3	1.07	0.26

Continue from table 3.4.

Liver / total viscera+organ wt, %	18.7	18.3	18.1	18.9	0.46	0.50

[x,y] Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means. n = 8 for basal, n = 7 for DDGS-BPX, n = 9 for DDGS-CV and HP-DDG.

[2]DDGS-BPX = distillers dried grains with soluble from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD); DDGS-CV = conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC., Palestine, IL); HP-DDG = high protein distillers dried grains (Poet Nutrition, Sioux Falls, SD).

[3]Basal = basal diet; DDGS-BPX = diet containing 70% of the basal diet and 30% of DDGS-BPX; DDGS-CV = diet containing 70% of the basal diet and 30% of DDGS-CV; HP-DDG = diet containing 70% of the basal diet and 30% of HP-DDG.

[4]Total organ weight = sum of the weights of liver, heart, kidney, lungs and spleen.

[5]Total weight = sum of hot carcass weight, and the weights of blood, full viscera, and total organ weight.

Table 3.5. Weights of carcass and body components of finishing pigs[1].

	Diet[2,3]					
	Basal	DDGS-BPX	DDGS-CV	HP-DDG	SEM	*P*-value
Live wt, kg	119.7	119.3	118.8	119.3	3.97	0.99
Hot carcass wt, kg	100.8	99.9	100.3	98.4	3.59	0.88
Dressing percentage, %	84.2[y]	83.6[xy]	84.4[y]	82.5[x]	0.47	0.01
Chilled carcass wt, kg	100.2	99.0	99.6	97.7	3.59	0.87
Blood wt, kg	4.35	4.53	4.20	4.47	0.174	0.57
Full viscera wt, kg	9.30	9.48	9.20	10.51	0.475	0.14
Full viscera wt, % of live wt	7.76	7.98	7.75	8.83	0.321	0.08
Empty viscera wt, kg	6.08	6.30	6.18	6.56	0.608	0.29
Empty viscera wt, % of live wt	4.98	5.21	5.15	5.41	0.456	0.22
Liver wt, kg	1.82	1.89	1.79	2.00	0.070	0.09
Heart wt, kg	0.44	0.43	0.45	0.44	0.019	0.87

Continue from table 3.5

Kidney wt, kg	0.46	0.46	0.45	0.50	0.019	0.14
Lungs wt, kg	1.46	1.54	1.42	1.62	0.107	0.55
Spleen wt, kg	0.22	0.22	0.21	0.22	0.011	0.64
Total organ wt[4], kg	4.39^{xy}	4.54^{xy}	4.31^{x}	4.78^{y}	0.115	0.04
Total viscera + organ wt, kg	10.5	10.9	10.5	11.3	0.66	0.06
Total wt[5], kg	118.9	118.5	118.0	118.2	3.96	1.00
Total digesta-free BW, kg	115.0	114.4	114.3	113.5	4.18	0.97
Chilled carcass wt / total digesta-free BW, %	87.1^{y}	86.6^{xy}	87.2^{y}	86.1^{x}	0.31	0.02
Empty viscera wt / total digesta-free BW, %	5.17	5.42	5.34	5.67	0.462	0.14
Total organ wt / total digesta-free BW, %	3.86^{xy}	4.02^{xy}	3.80^{x}	4.26^{y}	0.151	0.04
Total viscera+organ / total digesta-free BW, %	9.03^{x}	9.43^{xy}	9.13^{x}	9.92^{y}	0.386	0.02
Liver / total digesta-free BW, %	1.58^{x}	1.66^{xy}	1.58^{x}	1.78^{y}	0.053	0.01
Liver / total organ wt, %	41.5	41.6	41.6	41.9	1.51	1.00

Continue from table 3.5.

Liver / total viscera+organ wt, %	18.0	17.9	17.6	18.4	1.29	0.79

[x,y] Means within a row lacking a common superscript letter are different (P < 0.05).

[1]Data are least squares means. n = 9 for basal, n = 8 for DDGS-BPX, DDGS-CV, and HP-DDG.

[2]DDGS-BPX = distillers dried grains with soluble from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD); DDGS-CV = conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC., Palestine, IL); HP-DDG = high protein distillers dried grains (Poet Nutrition, Sioux Falls, SD).

Basal = basal diet; DDGS-BPX = diet containing 70% of the basal diet and 30% of DDGS-BPX; DDGS-CV=diet containing 70% of the basal diet and 30% of DDGS-CV; HP-DDG = diet containing 70% of the basal diet and 30% of HP-DDG.

[3]Total organ weight = sum of the weights of liver, heart, kidney, lungs and spleen.

[4]Total weight = sum hot carcass weight, and the weights of blood, full viscera, liver, heart, kidney, lungs, and spleen.

Table 3.6. 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[1].

		Diet[3,4]					
Item	ISG[2]	Basal	DDGS-BPX	DDGS-CV	HP-DDG	SEM	*P*-value
Body composition							
Digesta-free BW, kg	19.64	42.47[y]	38.50[x]	40.12[xy]	40.08[xy]	1.082	0.01
Digesta-free body DM, kg	5.64	14.69	13.09	13.64	13.62	0.538	0.11
Protein, g/kg	576	500[xy]	516[y]	482[xy]	472[x]	9.2	0.01
Lipid, g/kg	277	404	397	375	412	14.8	0.31
Energy, Mcal/kg	5.84	6.44	6.30	6.28	6.41	0.074	0.34
Total protein, kg/pig	3.24	7.33[y]	6.79[xy]	6.55[x]	6.42[x]	0.226	0.01
Total lipid, kg/pig	1.58	5.95	5.23	5.17	5.64	0.388	0.38
Total energy, Mcal/pig	32.99	94.63	82.70	85.93	87.47	4.162	0.15
Protein gain, g/d	-	149.7[y]	130.2[xy]	121.8[x]	117.1[x]	6.02	0.01

Continue from table 3.6

Lipid gain, g/d	-	158.8	133.1	130.3	147.1	13.27	0.38
Lipid:protein, g/g	-	1.06	1.01	1.05	1.25	0.078	0.13
MER,[5] Mcal/d	-	2.25	1.82	1.93	1.98	0.134	0.15
CER,[6] Mcal/d	-	2.35	1.99	1.92	2.05	0.152	0.19

[x,y]Means within a row lacking a common superscript letter are different (*P* < 0.05).

[1]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.

[2]ISG = initial slaughter group. Initial slaughter group was not included in analysis.

[3]DDGS-BPX = distillers dried grains with soluble from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD); DDGS-CV = conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC., Palestine, IL); HP-DDG = high protein distillers dried grains (Poet Nutrition, Sioux Falls, SD).

[4]Basal = basal diet; DDGS-BPX = diet containing 70% of the basal diet and 30% of DDGS-BPX; DDGS-CV = diet containing 70% of the basal diet and 30% of DDGS-CV; HP-DDG = diet containing 70% of the basal diet and 30% of HP-DDG.

[5]MER = measured energy retention.

[6]CER = calculated energy retention (calculated from protein and lipid gain as 5.66 and 9.46 kcal/g for protein and lipids, respectively).

Table 3.7. 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 lipid in finishing pigs[1].

		Dietary treatment[3,4]					
Item	ISG[2]	Basal	DDGS-BPX	DDGS-CV	HP-DDG	SEM	*P*-value
Body composition							
Digesta-free BW, kg	82.96	115.46	114.86	114.74	113.96	3.808	0.98
Digesta-free body DM, kg	33.88	50.12	49.03	51.44	49.06	2.114	0.64
Protein, g/kg	400	364	382	348	372	10.0	0.14
Lipid, g/kg	509	547^{xy}	512^{x}	564^{y}	530^{xy}	10.4	0.01
Energy, Mcal/kg	6.94	7.15^{yz}	6.94^{x}	7.16^{z}	7.0^{xy}	0.051	0.01
Total protein, kg/pig	13.48	18.12	18.47	17.80	18.10	0.630	0.78
Total lipid, kg/pig	17.32	27.57	25.27	29.04	26.05	1.492	0.14
Total energy, Mcal/pig	235.4	359.2	340.8	368.9	343.9	16.58	0.32
Protein gain, g/d	-	146.5	139.9	132.4	135.2	10.34	0.78

Continue from table 3.7

Lipid gain, g/d	-	312.2^{xy}	219.5^{x}	345.6^{y}	252.6^{xy}	30.06	0.02
Lipid:protein, g/g	-	2.25	1.60	2.98	1.90	0.360	0.07
MER,[5] Mcal/d	-	3.80^{xy}	2.92^{x}	3.94^{y}	3.13^{xy}	0.281	0.03
CER,[6] Mcal/d	-	3.78^{xy}	2.86^{x}	4.02^{y}	3.15^{xy}	0.282	0.02

^{x,y} Means within a row lacking a common superscript letter are different (P < 0.05).

[1] 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.

[2]ISG = initial slaughter group. Initial slaughter group was not included in analysis.

[3]DDGS-BPX = distillers dried grains with soluble from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD); DDGS-CV = conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC., Palestine, IL); HP-DDG = high protein distillers dried grains (Poet Nutrition, Sioux Falls, SD).

[4]Basal = basal diet; DDGS-BPX = diet containing 70% of the basal diet and 30% of DDGS-BPX; DDGS-CV = diet containing 70% of the basal diet and 30% of DDGS-CV; HP-DDG = diet containing 70% of the basal diet and 30% of HP-DDG.

[5]MER = measured energy retention.

[6]CER = calculated energy retention (calculated from protein and lipid gain as 5.66 and 9.46 kcal/g for protein and lipids, respectively).

Table 3.8. Net energy of diets and ingredients fed to growing and finishing pigs[1].

	Dietary treatment[2,3]					
Item	Basal	DDGS-BPX	DDGS-CV	HP-DDG	SEM	*P*-value
Growing pigs						
Initial body energy, Mcal	31.77	32.15	31.91	31.91	1.070	0.87
Final body energy, Mcal	94.63	82.70	85.93	87.47	4.162	0.15
Energy retention, Mcal	62.93	50.91	54.02	55.55	3.762	0.15
Total ONE_m,[4] Mcal	29.21	28.58	28.92	28.85	0.459	0.53
Total NE intake, Mcal	92.13	79.41	82.94	84.40	4.089	0.15
Total feed intake, kg	52.83	46.87	48.05	48.13	2.031	0.16
NE of diets, kcal/kg	1,744	1,698	1,720	1,756	38.9	0.74
NE of ingredient,[5] kcal/kg	-	1,596	1,665	1,783	135.5	0.47
Finishing pigs						
Initial body energy, Mcal	226.30	238.58	230.54	234.02	9.038	0.30

Continue from table 3.8.

Final body energy, Mcal	359.22	340.80	368.92	343.94	16.58	0.32
Energy retention, Mcal	132.92^{xy}	102.03^{x}	138.03^{y}	109.57^{xy}	9.820	0.03
Total ONE_{m},[4] Mcal	125.20	125.89	125.74	125.62	2.692	0.99
Total NE intake, Mcal	258.12	227.96	263.95	235.37	11.76	0.06
Total feed intake, kg	120.76	107.9	114.35	108.44	5.531	0.17
NE of diets, kcal/kg	2,140	2,129	2,299	2,171	65.57	0.24
NE of ingredient,[5] kcal/kg	-	2,065^{x}	2,718^{y}	2,291^{xy}	223.4	0.05

^{x,y} Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]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.

[2]DDGS-BPX = distillers dried grains with solubles from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD); DDGS-CV = conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC., Palestine, IL); HP-DDG = high protein distillers dried grains (Poet Nutrition, Sioux Falls, SD).

Continue from table 3.8.

[3]Basal = basal diet; BPX = diet containing 70% of the basal diet and 30% of DDGS-BPX; DDGS-CV = diet containing 70% of basal diet and 30% of DDGS-BPX; HP-DDG = diet containing 70% of basal diet and 30% of HP-DDG.

[4]Total operational NE requirement for maintenance is calculated by multiplying the mean metabolic BW ($kg^{0.6}$) of each pig by 128 and 219 kcal for growing and finishing pigs, respectively (Kil, 2008) and the number of days on experiments (28 d for growing and 35 d for finishing pigs).

[5]NE of DDGS-BPX, DDGS-CV, or HP-DDG. The NE of the ingredients was calculated using the difference method by subtracting the NE contributed by the basal diet from the NE of the diets containing DDGS-BPX, DDGS-CV, or HP-DDG (de Goey and Ewan, 1975).

Table 3.9. Comparison of NE values for diets and ingredients between growing and finishing pigs[1].

	NE, kcal/kg			
Item	Growing	Finishing	SEM	*P*-value
Diets[2]				
Basal	1,745	2,140	52.6	<0.001
DDGS-BPX	1,699	2,131	74.3	<0.001
DDGS-CV	1,720	2,292	34.1	<0.001
HP-DDG	1,756	2,164	49.8	<0.001
Ingredients[3]				
DDGS-BPX	1,593	2,109	247.6	0.16
DDGS-CV	1,665	2,647	113.7	<0.001
HP-DDG	1,783	2,220	170.9	0.09

[1]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, DDS-CV, and HP-DDG.

[2]Basal = basal diet; DDGS-BPX = diet containing 70% of the basal diet and 30% of DDGS-BPX; DDGS-CV = diet containing 70% of the basal diet and 30% of DDGS-CV; HP-DDG = diet containing 70% of the basal diet and 30% of HP-DDG.

[3]DDGS-BPX = distillers dried grains with soluble from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD); DDGS-CV = conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC., Palestine, IL); HP-DDG = high protein distillers dried grains (Poet Nutrition, Sioux Falls, SD).

Table 3.10. Effects of ingredient and stage of growth on the NE of distillers dried grains with soluble (DDGS) and high protein distillers dried grains (HP-DDG)[1].

	Stage of growth[2]		Ingredient[3]				*P*-value[4]	
Items	G	F	DDGS-BPX	DDGS-CV	HP-DDG	SEM	Ingredient	Stage
NE value, kcal/kg	1,671	2,325	1,841	2,146	2,008	112.2	0.258	<0.001

[1]Data are least squared means of 25 observations for growing pigs and 24 observations for finishing pigs.

[2]Stage of Growth = growing pigs (G) and finishing pigs (F).

[3]DDGS-BPX = distillers dried grains with solubles from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD); DDGS-CV = conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC., Palestine, IL); HP-DDG = high protein distillers dried grains (Poet Nutrition, Sioux Falls, SD).

[4]*P*-values for the effects of ingredient and stage of growth on NE of DDGS-BPX, DDGS-CV, and HP-DDG. No interaction was observed between ingredient and stage of growth.

CHAPTER 4

ENERGY AND NUTRIENT DIGESTIBILITY OF DISTILLERS DRIED GRAINS WITH SOLUBLES AND HIGH PROTEIN DISTILLERS DRIED GRAINS FED TO GROWING AND FINISHING PIGS

ABSTRACT

An experiment was conducted to determine the concentration of DE and ME and the apparent ileal digestibility (AID) and apparent total tract digestibility (ATTD) of energy and nutrients in distillers dried grains with solubles (DDGS) and in high protein distillers dried grains (HP-DDG) fed to growing and finishing pigs. One source of conventional DDGS (DDGS-CV), 1 source of uncooked DDGS (DDGS-BPX), and 1 source of HP-DDG were used. A total of 16 growing pigs (initial BW: 24.3 ± 3.41 kg BW) and 16 finishing pigs (initial BW: 91.9 ± 20.2 kg BW) were fitted with a T-cannula in the distal ileum and allotted to 4 dietary treatment groups in a 2-period crossover design. Feed was provided in the amount of 3 times the estimated energy requirement for maintenance. Pigs were housed individually in metabolism crates with free access to water throughout the experiment. Treatments included a basal diet containing mainly corn and soybean meal and 3 diets that were formulated by mixing 70% of the basal diet and 30% DDGS-CV, DDGS-BPX, or HP-DDG. For each stage of growth, experimental diets were fed in 2 periods of 7 d each. Total fecal materials and urine were collected twice daily, and ileal samples were collected on d 13 and 14 of each period. Results showed that for both growth stages, the ATTD of GE was greater ($P < 0.05$) for HP-DDG than for DDGS-BPX or DDGS-CV. In growing pigs, therefore, the DE and ME of HP-DDG (4,288 and 4,024 kcal/kg of DM, respectively) were greater ($P < 0.05$) than the DE and ME of DDGS-BPX (4,008 and

3,740 kcal/kg of DM, respectively), but the DE and ME of DDGS-CV (4,113 and 3,935 kcal/kg of DM, respectively) were not different from the DE and ME of HP-DDG or DDGS-BPX. In finishing pigs, the DE and ME did not differ among ingredients (4,084, 4,061, and 4,362 kcal DE/kg of DM; 3,882, 3864, and 4,045 kcal ME/kg of DM for DDGS-BPX, DDGS-CV, and HP-DDG, respectively). For both growth stages, the AID of nutrients was not different among ingredients. The ATTD of CP, OM and carbohydrates was, however, greater ($P < 0.05$) in HP-DDG than in DDGS-BPX and DDGS-CV, but the ATTD of acid hydrolyzed ether extract was greater in DDGS-BPX and DDGS-CV than in HP-DDG. In conclusion, the ME of DDGS-BPX, DDGS-CV, and HP-DDG were similar for finishing pigs, but the ME in HP-DDG was greater than in DDGS-BPX, but not different from DDGS-CV when fed to growing pigs.

Key words: Distillers dried grains with solubles, high-protein distillers dried grains, DE, ME, pigs.

INTRODUCTION

Distillers dried grains with solubles (**DDGS**) is a co-product from the ethanol distillation industry that is available for swine diets due to the increasing production of fuel from corn. However, variability in energy and nutrient digestibility as a result of differences in chemical composition among DDGS sources has been reported (Spiehs et al., 2002; Shurson and Alghamdi, 2008).

Energy digestibility has been measured in high protein distillers dried grains (**HP-DDG**) and conventional DDGS (Stein et al., 2006; Pedersen et al., 2007; Widmer et al., 2007). In conventional DDGS, the average total tract digestibility (**ATTD**) of GE is lower than in HP-DDG and corn (Stein, 2008), because the fiber concentration in DDGS is greater than in HP-DDG and corn (Stein and Shurson, 2009). As a consequence, DE and ME in DDGS are similar to that in corn, but DE and ME in HP-DDG are greater than in DDGS and corn (Pedersen et al., 2007; Widmer et al., 2007). The DE and ME of HP-DDG are greater than in corn because of the greater GE in HP-DDG, which is a result of the high concentration of CP in HP-DDG.

Nutrient digestibility in DDGS and HP-DDG has also been measured. Widmer et al. (2007) reported greater apparent ileal digestibility (**AID**) for CP and AA in HP-DDG than in conventional DDGS. The ATTD of ether extract in DDGS has also been reported (Stein et al., 2009), but there is no information about the ATTD of ether extract in HP-DDG.

Distillers dried grains with solubles may also be produced using the BPX technology, which uses enzymes to predigest the starch prior to yeast fermentation. The DDGS that is produced using this technology is called DDGS-BPX. There are, however, no data on energy and nutrient digestibility in DDGS-BPX. The objective of this experiment is, therefore, to measure the DE and ME in growing and finishing pigs of conventional DDGS, DDGS-BPX, and HP-DDG, as well as to measure the ATTD and AID of nutrients in these 3 sources of corn distillers co-products.

MATERIALS AND METHODS

Animals, Housing, and Experimental Design

The protocol for the experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. Sixteen growing and 16 finishing barrows originating from the matings of line 337 sires to C-22 females (Pig Improvement Company, Hendersonville, TN) were obtained from the University of Illinois Swine Research Center. The average initial BW was 24.3 ± 3.41

kg and 91.9 ± 20.2 kg for the growing and finishing pigs, respectively. All animals were equipped with a T-cannula in the distal ileum using procedures described by Stein et al. (1998). Within each stage of growth, pigs were randomly allotted to 4 dietary treatment groups in a 2-period crossover design, for a total of 8 observations per treatment. Pigs were housed individually in metabolism crates equipped with a bowl shaped drinker and a feeder in an environmentally controlled building.

Dietary Treatments

Diets and sources of DDGS and HP-DDG (Table 4.1) that were used in this experiment were identical to those used in a previous experiment (Chapter 2). In short, for each stage of growth, dietary treatments consisted of a basal diet containing mainly corn and soybean meal and 3 diets that were formulated by mixing 70% of the basal diet and 30% DDGS-CV, DDGS-BPX, or HP-DDG (Table 4.2). Chromic oxide was included in all diets as an indigestible marker.

The daily feed allowance was calculated as 3 times the estimated energy requirement for maintenance (i.e., 106 kcal ME/kg $BW^{0.75}$; NRC 1998). The BW of growing pigs was recorded at the initiation of each period and the average BW of all pigs was used to calculate the feed allowance for the following period. For finishing pigs, however, the daily feed allowance was calculated using the average BW of pigs within each replication. All diets were provided in a meal form, and daily feed allowance was divided into 2 equal meals that were fed at 700 and 1600.

Sample Collection

At each stage of growth, the experiment consisted of 2 periods of 14 d. After a 5 d adaptation period to the experimental diets, total fecal materials and urine were collected twice daily and stored at -20°C. Ferric oxide was included in the morning meals on d 6 and 11 and the marker to marker approach was used to indicate start and conclusion of fecal collections (Adeola, 2001). Urine was collected over a preservative solution of 50 ml of 6N HCL. At each collection, a 20% sub-sample was collected and stored at -20^{o}C. On d 13 and 14, ileal samples were collected using procedures previously described by Stein et al. (2006). Prior to chemical analysis, ileal and urine sub-samples were lyophilized to a constant weight and ileal and fecal samples were finely ground.

Chemical Analysis

Samples were analyzed in duplicates and analyses were repeated if results from the duplicate samples varied more than 5% from the mean. Fecal samples were dried at 60^{o}C in a forced air oven, weighed, and then ground and a sub-sample for analysis was collected. The DM of diets, ingredients, feces, and ileal digesta samples was determined by oven drying at 135°C for 2 h (method 930.15; AOAC, 2005). The ash concentration of diets, ingredients, feces and ileal digesta samples was determined by oven drying at 600°C for 2 h (method 942.05; AOAC, 2005).

The GE of diets, ingredients, feces, and ileal digesta samples were determined on an adiabatic bomb calorimeter (model 6300, Parr Instruments, Moline, IL) using benzoic acid as a calibration standard. The N concentration of diets, ingredients, feces, and ileal digesta samples was determined using the combustion method (method 968.06; AOAC, 2005) on an Elementar Rapid N-cube protein/nitrogen apparatus (Elementar Americas Incorporated, Mt. Laurel, NJ), using aspartic acid as a calibration standard.

The concentration of total lipids in diets, ingredients, feces, and ileal digesta samples was determined after acid hydrolysis using 3 N hydrochloric acid followed by petroleum ether extraction (method 996.01;AOAC, 2005) using a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). Chromium concentrations of diets and ileal digesta samples were determined after nitric acid-perchloric acid wet ash sample preparation (method 990.08, AOAC 2005).

Calculations and Statistical Analysis

The concentrations of total carbohydrates (**CHO**) in diets, feces, and ileal digesta was calculated as follows:

CHO = 100 – (CP + AEE + ash + (100-DM))

where AEE is acid hydrolyzed ether extract.

The ATTD of energy, DM, CP, AEE, CHO, and OM and the DE and ME of each diet were calculated as outlined by Adeola (2001). The DE and ME of DDGS-BPX, DDGS-CV, and HP-DDG were calculated using the difference procedure (Pedersen et al., 2007).The AID of DM, CP, AEE, GE, CHO, and OM were also calculated (Stein et al., 2007) for each diet. The difference procedure was used to calculate the ATTD and AID of GE, CP, AEE, CHO, and OM in DDGS-BPX, DDGS-CV, and HP-DDG.

All data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC) with the individual pig as the experimental unit. Homogeneity of the variances was verified using the UNIVARIATE procedure of SAS. The residual vs. the predicted plot procedure was used to analyze for outliers, but no values were identified as outliers. Period was included in the model as a random effect. The differences among treatments were determined using ANOVA, 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.

RESULTS

All pigs in both stages of growth readily consumed all the feed offered during the experiment, but 1 growing pig had to be replaced in the first period because of poor health. The calculated GE concentration (kilocalories/kilogram) was similar for the DDGS-BPX, DDGS-CV, and HP-DDG diets, but lower for the basal diet (Table 4.2). As expected, for both growing and finishing pigs, the CP concentration in the HP-DDG diet was greater than in the DGGS-BPX, DDGS-CV, and the basal diet.

In growing pigs, the fecal energy excretion was lower ($P < 0.05$) for pigs fed the basal diet than for pigs fed the other diets, but pigs fed the 2 DDGS diets excreted more ($P < 0.05$) energy in the feces than pigs fed the HP-DDG diet (Table 4.3). The ATTD of GE was greater ($P < 0.05$) for pigs fed the basal diet (89.0%) than for pigs fed the other diets, but pigs fed the HP-DDG diet had greater ($P < 0.05$) ATTD (85.3%) of GE than pigs fed the DDGS-BPX (83.4%) or DDGS-CV (83.6%) diets. The energy excreted in the urine did not differ among diets. The DE of the HP-DDG diet (3,622 kcal/kg) was greater ($P < 0.05$) than the DE of the basal, DDGS-BPX, and DDGS-CV diets (3,485, 3,508, and 3,547 kcal/kg, respectively). The ME of the HP-DDG (3,463 kcal/kg) was greater (P < 0.05) than the ME of the basal (3,361 kcal/kg) and DDGS-BPX (3,349 kcal/kg) diets. Likewise, the ME of the DDGS-CV diet (3,413 kcal/kg) was also greater ($P < 0.05$) than for the DDGS-BPX diet, but not different from the basal diet.

In finishing pigs, the fecal energy excretion was greater ($P <0.05$) for pigs fed the 2 DDGS diets than for pigs fed the basal diet, but the fecal energy of pigs fed the HP-DDG diet was not different from that of pigs fed any of the other diets (Table 4.4). The ATTD of GE was greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the DDGS-BPX or the DDGS-CV diets (86.2 vs. 81.0 and 81.4%). The ATTD of GE in the HP-DDG diet (84.0%) was also greater ($P < 0.05$) than for pigs fed the DDGS-CV diet, but not different from pigs fed the basal or the DDGS-BPX diets. The daily excretion of urine was greater in pigs fed the HP-DDG (360.2 kcal) than for pigs fed the basal diet (195.3 kcal), but not different from that of pigs fed the DDGS-BPX and the DDGS-CV diets (294.6 and 282.0 kcal, respectively). The DE of the HP-DDG diet was greater ($P < 0.05$) than the DE of the basal diet, the DDGS-BPX diet, and the DDGS-CV diet (3,549 vs. 3,351, 3,434, and 3,440 kcal/kg). The ME in the HP-DDG diet (3,414 kcal) was also greater than the ME in the basal diet (3,283 kcal/kg), but not different than the ME of the DDGS-BPX and the DDGS-CV diets (3333 and 3333 kcal/kg, respectively).

In growing pigs, the DE and ME of HP-DDG (4,288 and 4,024 kcal/kg of DM) were greater ($P < 0.05$) than in DDGS-BPX (4,008 and 3,740 kcal/kg of DM), but the DE and ME of DDGS-CV (4,113 and 3,935 kcal/kg of DM) were not different from that of the other 2 ingredients (Table 4.5). In finishing pigs, the DE and ME (as-fed basis) of HP-DDG (4,010 and 3,719 kcal/kg) were also greater ($P < 0.05$) than in DDGS-BPX (3,628 and 3,448 kcal/kg) or DDGS-CV (3,646 and 3,469 kcal/kg). However, when calculated on a DM-basis, no differences between the 3 ingredients were observed (Table 4.6).

For growing and finishing pigs, the AID of CP, AEE, OM, and CHO was not different among ingredients (Table 4.7). The AID of CP, however, tended ($P < 0.129$) to be greater in HP-DDG than in DDGS-BPX or DDGS-CV. For both growing and finishing pigs, the ATTD of CP, OM, and CHO (%) was greater ($P < 0.05$) for HP-DDG than for DDGS-BPX or DDGS-CV (Table 4.8). In growing pigs, the ATTD of AEE was greater ($P < 0.05$) in DDGS-BPX than in HP-DDG, but the ATTD of AEE in DDGS-CV was not different from the other diets.

DISCUSSION

The concentration of CP in DDGS and HP-DDG used in this experiment are similar to values previously reported (NRC, 1998; Spiehs et al., 2002; Stein et al., 2006; Pedersen et al., 2007; Widmer et al., 2007). The concentration of ether extract in DDGS-CV is, however, 2 or 3 percentage units greater than the values reported by Spiehs et al. (2002) and Pedersen et al. (2007), and ether extract in DDGS-BPX and HP-DDG are close to the values that were measured by Pedersen et al. (2007) and by Widmer et al. (2007), respectively. The AEE concentration in DDGS or HP-DDG has not been previously reported. The concentration of ADF in DDGS-BPX is lower than previously reported values (Stein et al., 2006; Pedersen et al., 2007; Stein and Shurson, 2009), but ADF in DDGS-CV agree with values reported by Stein et al. (2006), and Stein and Shurson (2009). The concentration of NDF in DDGS-BPX is also within the range of values previously reported (Stein and Shurson, 2009), but is greater in DDGS-CV than values measured by Pedersen et al. (2007). For both DDGS sources, NDF concentration is, however, lower than values measured by Stein et al. (2006). In HP-DDG, the concentration of ADF was slightly greater than previous measured values, and the concentration of NDF was much greater than values reported by Widmer et al. (2007). The TDF in the 3 sources of corn distillers co-products is lower than values reported by Stein and Shurson (2009).

In growing and finishing pigs, the concentration of DE and ME in DDGS-BPX and DDGS-CV agree with reported values for DE and ME in DDGS (Pedersen et al., 2007, Stein and Shurson, 2009). The ATTD of GE in DDGS-BPX and DDGS-CV for growing pigs is 70.4 and 71.0%, respectively, and for finishing is 72.3 and 70.3%, respectively; whereas, the ATTD of GE in corn was 90.4 (Pedersen et al., 2007). Values between 73.9 and 82.8 % for ATTD of GE in DDGS were previously reported (Stein and Shurson, 2009). The lower ATTD of GE in DDGS compared with corn is probably the result of increased concentration of ADF and NDF in DDGS, because the ATTD of GE is negatively associated with the concentration of fiber in a feedstuff (Noblet and Le Goff, 2001). As a consequence, the DE and ME in DDGS is lower than in corn. In growing and finishing pigs, values for DE and ME in HP-DDG are lower than values for DE and ME in HP-DDG reported by Widmer et al. (2007). Likewise, the ATTD of GE in HP-DDG obtained in the present study is lower than the ATTD of GE (88.2%) reported by Widmer et al. (2007). The lower ATTD of GE is likely a result of the much greater concentration of NDF (30.4 vs. 16.4 %) in the source of HP-DDG used in the present study.

For growing and finishing pigs, the ATTD of AEE in both DDGS sources was greater than values of ATTD of ether extract reported by Stein et al. (2009). The reason for this observation may be that the DDGS used by Stein et al. (2009) had a greater concentration of fiber than the DDGS sources used in the present experiment, because dietary fiber has a negative impact on the digestibility of ether extract (Just, 1982; Noblet and Shi, 1993). Another possible reason is that high fiber content may also increase the endogenous losses of fat because of increased microbial activity in the hindgut, which will reduce the ATTD of fat (Back Knudsen and Hansen, 1991).

The AID of AEE, although slightly lower, was similar to the ATTD of AEE, which indicates that there is no absorption of lipids in the hindgut (Kil et al., 2007). Values for AID or ATTD of AEE in HP-DDG have not been previously reported. Because of hindgut fermentation of dietary fiber in both DDGS and HP-DDG, the ATTD of CHO was greater than the AID for both growing and finishing pigs.

The GE concentration is not different in HP-DDG than in DDGS-CV or DDGS-BPX. The values of GE obtained in the present experiment agree with GE values reported by Widmer et al. (2007) for GE in HP-DDG, and values from Pedersen et al. (2007) for GE in DDGS. However, the ATTD of GE is lower for DDGS-BPX and DDGS-CV than for HP-DDG. As a consequence, for growing pigs, HP-DDG has a greater DE and ME than DDGS-CV or DDGS-BPX but this was not the case for finishing pigs.

For both growing and finishing pigs, the ATTD of AEE was greater in DDGS-BPX and DDGS-CV than in HP-DDG. A possible reason is the greater content of lipids in DDGS than in HP-DDG, because the relative effect of endogenous losses on the ATTD of lipids decreases as the concentration of dietary lipids increases, leading to a greater measured value for ATTD of lipids at high levels of dietary lipids (Jørgensen et al., 1993; Kil et al., 2007, Stein et al., 2009). The greater NDF and ADF concentration in DDGS-CV than in DDGS-BPX is likely the reason for reduced ATTD of AEE in DDGS-CV compared with DDGS-BPX.

In conclusion, data from the present experiment showed that the DE and ME may be affected by the source of corn distillers co-products in both growing and finishing pigs, however no differences were observed between DDGS-BPX and DDGS-CV for both growth stages. The AID was not different among ingredients, and the ATTD of CP, OM, and CHO were greater in HP-DDG than in the 2 sources of DDGS, but that was not the case for AEE.

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Table 4.1. Analyzed composition of distillers dried grains with solubles (DDGS) and high protein distillers dried grains (HP-DDG) as fed basis (except dry matter).

	Ingredient[1]		
Composition	DDGS-BPX	DDGS-CV	HP-DDG
DM, %	88.83	89.79	91.94
GE, Mcal/kg	4.88	5.01	5.01
CP, %	27.19	28.35	40.52
Ether extract, %	11.18	13.01	3.07
AEE[2], %	13.23	14.16	6.05
Ash, %	5.77	4.79	2.36
Total dietary fiber,%	28.77	28.48	28.06
ADF, %	7.52	9.71	10.29
NDF, %	28.38	35.12	30.37

[1]DDGS-BPX = distillers dried grains with solubles from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD); DDGS-CV = conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC., Palestine, IL); HP-DDG = high protein distillers dried grains (Poet Nutrition, Sioux Falls, SD).

[2]AEE = acid hydrolyzed ether extract.

Table 4.2. 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, %								
Ground corn	66.10	46.27	46.27	46.27	80.00	56.00	56.00	56.00
Soybean meal, 48%	28.00	19.60	19.60	19.60	16.50	11.55	11.55	11.55
DDGS-BPX	-	30.00	-	-	-	30.00	-	-
DDGS-CV	-	-	30.00	-	-	-	30.00	-
HP-DDG	-	-	-	30.00	-	-	-	30.00
Soybean oil	2.00	1.40	1.40	1.40	-	-	-	-
Limestone	1.50	1.05	1.05	1.05	1.50	1.05	1.05	1.05
Monocalcium phosphate	0.70	0.49	0.49	0.49	0.60	0.42	0.42	0.42
Cr_2O_3	0.50	0.35	0.35	0.35	0.50	0.35	0.35	0.35

Continue from table 4.2.

Vitamin-mineral premix	0.45	0.32	0.32	0.32	0.40	0.28	0.28	0.28
Salt	0.60	0.42	0.42	0.42	0.50	0.35	0.35	0.35
Tylan® Premix[3]	0.15	0.10	0.10	0.10	-	-	-	-
Energy and nutrients[1]								
GE, Mcal/kg	3,916	4,205	4,244	4,244	3,888	4,186	4,225	4,225
ME, Mcal/kg	3,380	3,391	3,391	3,607	3,294	3.330	3,330	3,547
DM, %	87.71	89.36	88.74	89.56	88.35	89.02	89.17	89.88
Ash, %	6.25	5.76	5.57	4.78	4.81	5.01	4.77	3.95
CP, %	20.38	21.44	22.05	26.00	14.39	18.80	18.49	21.92
Ether extract, %	4.01	6.52	6.87	4.05	3.00	5.50	6.62	3.04
AEE[3], %	4.90	7.85	8.10	5.47	3.66	6.84	7.38	5.19
Total dietary fiber, %	10.68	15.90	14.24	15.51	10.34	16.55	15.96	16.67
ADF, %	2.94	4.45	4.45	5.22	3.01	4.33	5.06	5.43

Continue from table 4.2.

NDF, %	8.65	26.42	15.57	13.67	10.08	15.62	23.70	18.06
Ca, %	0.80	0.62	0.62	0.57	0.75	0.59	0.59	0.53
Bioavailable P, %	0.04	0.27	0.27	0.20	0.16	0.25	0.25	0.17

[1]Tylosin phosphate. Elanco Animal Health. Indianapolis, IN.

[2]Values for ME, Ca, and bioavailable P were calculated (NRC, 1998); all other values were analyzed.

[3]AEE = acid hydrolyzed ether extract.

Table 4.3. Energy digestibility and retention of growing pigs fed experimental diets (as-fed basis)[1].

	Diet[2]					
Items	Basal	DDGS-BPX	DDGS-CV	HP-DDG	SEM	*P*-value
GE intake, kcal/d	4,041	4,327	4,367	4,104	127	0.207
Fecal energy, kcal/d	443.7[c]	716.4[a]	716.3[a]	599.3[b]	20.5	< 0.001
ATTD of GE, %	89.0[a]	83.4[c]	83.6[c]	85.3[b]	0.39	< 0.001
Diet DE, kcal/kg	3,485[b]	3,508[b]	3,547[b]	3,622[a]	16.3	< 0.001
Urine energy, kcal/d	129.0	165.0	139.6	154.5	15.6	0.393
Diet ME, kcal/kg	3,361[bc]	3,349[c]	3,413[ab]	3,463[a]	16.3	< 0.001

[a-c] Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means. n = 8.

[2]Basal = basal diet; DDGS-BPX = diet containing 70% of basal diet and 30% of DDGS-BPX; DDGS-CV= diet containing 70% of basal diet and 30% of DDGS-CV; HP-DDG = diet containing 70% of basal diet and 30% of HP-DDG.

Table 4.4. Energy digestibility and retention of finishing pigs fed experimental diets (as-fed basis)[1].

Items	Diet[2]				SEM	*P*-value
	Basal	DDGS-BPX	DDGS-CV	HP-DDG		
GE intake, Mcal/d	11.04	11.80	11.91	11.24	0.72	0.779
Fecal energy, kcal/d	1,536[b]	2,123[a]	2,223[a]	1,791[ab]	170	0.001
ATTD of GE, %	86.2[a]	81.0[bc]	81.4[c]	84.0[ab]	0.64	< 0.001
Diet DE, kcal/kg	3,351[b]	3,434[b]	3,440[b]	3,549[a]	26.5	< 0.001
Urine energy, kcal/d	195.3[b]	294.6[ab]	282.0[ab]	360.2[a]	77.4	0.007
Diet ME, kcal/kg	3,283[b]	3,333[ab]	3,333[ab]	3,414[a]	24.8	< 0.009

[a-c] Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means. n = 8.

[2]Basal = basal diet; DDGS-BPX = diet containing 70% of basal diet and 30% of DDGS-BPX; DDGS-CV= diet containing 70% of basal diet and 30% of DDGS-CV; HP-DDG = diet containing 70% of basal diet and 30% of HP-DDG.

Table 4.5. Energy values for distillers dried grains with solubles (DDGS) and high protein distillers dried grains (HP-DDG) fed to growing pigs[1].

	Ingredient				
	DDGS-BPX	DDGS-CV	HP-DDG	SEM	*P*-value
ATTD of GE, %	70.4[b]	71.0[b]	76.9[a]	1.45	0.008
As-fed basis					
DE, kcal/kg	3,561[b]	3.693[ab]	3,943[a]	61.4	< 0.001
ME, kcal/kg	3,322[b]	3,533[ab]	3,700[a]	61.3	0.001
DM basis					
DE, kcal/kg	4,008[b]	4,113[ab]	4,288[a]	68.1	0.027
ME, kcal/kg	3,740[b]	3,935[ab]	4,024[a]	67.7	0.022

[a,b] Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means. n = 8.

Table 4.6. Energy values for distillers dried grains with solubles (DDGS) and high protein distillers dried grains (HP-DDG) fed to finishing pigs[1].

	Ingredient				
	DDGS-BPX	DDGS-CV	HP-DDG	SEM	*P*-value
ATTD of GE, %	72.3[b]	70.3[b]	78.9[a]	2.3	0.039
As-fed basis					
DE, kcal/kg	3,628[b]	3,646[b]	4,010[a]	96.9	0.017
ME, kcal/kg	3,448[b]	3,469[b]	3,719[a]	86.3	0.007
DM basis					
DE, kcal/kg	4,084	4,061	4,362	107	0.112
ME, kcal/kg	3,882	3,864	4,045	96.0	0.357

[a,b] Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means. n = 8.

Table 4.7. Apparent ileal digestibility (AID) of nutrients in ingredients in growing and finishing pigs (as-fed basis)[1].

	Ingredient[2]				
	DDGS-BPX	DDGS-CV	HP-DDG	SEM	*P*-value
Growing pigs					
CP, %	66.49	61.58	74.00	4.16	0.129
AEE[3], %	82.22	74.62	73.83	3.49	0.196
OM, %	52.44	52.46	57.06	4.16	0.669
CHO, %	36.93	39.70	40.42	5.17	0.882
Finishing pigs					
CP, %	72.18	72.77	76.35	1.51	0.132
AEE, %	85.74	79.58	80.43	2.07	0.107
OM, %	49.22	54.27	55.07	2.86	0.328
CHO, %	20.75	32.39	30.50	4.67	0.206

[a,b,c,] Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means. n = 8.

[2]DDGS-BPX = distillers dried grains with solubles from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD); DDGS-CV = conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC., Palestine, IL); HP-DDG = high protein distillers dried grains (Poet Nutrition, Sioux Falls, SD).

[3]AEE = acid hydrolyzed ether extract.

Table 4.8. Apparent total tract digestibility (ATTD) of nutrients in ingredients in growing and finishing pigs (as-fed basis)[1].

	Ingredient[2]				
	DDGS-BPX	DDGS-CV	HP-DDG	SEM	*P*-value
Growing pigs					
CP, %	73.76[b]	75.22[b]	83.79[a]	1.86	0.002
AEE[3], %	86.73[a]	81.13[ab]	75.01[b]	2.25	0.005
OM, %	71.52[b]	72.94[b]	78.89[a]	1.33	0.002
CHO, %	65.96[b]	68.85[b]	75.36[a]	1.57	0.001
Finishing pigs					
CP, %	78.69[b]	80.57[b]	86.71[a]	2.15	0.039
AEE, %	85.61[a]	80.96[a]	73.24[b]	2.41	0.001
OM, %	72.34[b]	71.64[b]	81.16[a]	2.06	0.006
CHO, %	63.46[b]	62.18[b]	77.70[a]	1.70	< 0.001

[a,b,c,] Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means. n = 8.

[2]DDGS-BPX = distillers dried grains with solubles from Dakota Gold BPX® (Poet Nutrition, Sioux Falls, SD); DDGS-CV = conventional distillers dried grains with solubles (Lincolnland Agri-Energy, LLC., Palestine, IL); HP-DDG = high protein distillers dried grains (Poet Nutrition, Sioux Falls, SD).

[3]AEE = acid hydrolyzed ether extract.