RESEARCHREPORT

ANIMAL SCIENCE — Nutritional Efficiency Consortium

Title: Net energy of three sources of distillers dried grains with solubles fed to growing and finishing pigs - **NPB**: #07-172.

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INDUSTRY SUMMARY

In North America, when energy is considered in formulation of swine diets, it is usually expressed as either digestible energy (DE) or metabolizable energy (ME). An energy system includes energy requirements and energy contributions of feedstuffs and diets, all expressed in the same units. However, DE and ME are energy systems that share important shortcomings: they systematically overvalue fibrous or high-protein feedstuffs and they systematically undervalue fats. These deficiencies in measurement of dietary energy are very important to the economics of pig production and there is, therefore, an increasing interest in using a system based on net energy (NE) of feed ingredients rather than DE or ME. It has been suggested that profits from pig production in North America would be improved by $2 to 3 per pig if diets were formulated based on a NE system rather than a DE or ME system. There are, however, no NE values for co-products from the dry grind ethanol industry such as distillers dried grains with solubles (**DDGS**) and high protein distillers dried grains with solubles (**HP-DDG**). The current research was, therefore, conducted to measure NE values in two sources of DDGS and in HP-DDG. The two sources of DDGS was a conventional DDGS (**DDGS-CV**) and a DDGS produced from uncooked corn (**DDGS-BPX**). The source of DDGS-CV that was used in this experiment had a greater concentration of fat then the DDGS-BPX that was used. The NE values were measured in growing as well as in finishing pigs to test the hypothesis that finishing pigs will be better able to digest the nutrients in DDGS than are growing pigs.

These research results were submitted in fulfillment of the Nutritional Efficiency Consortium research projects.
Contributing organizations for 2007 include: Arizona Pork Council, DPI Global, Eli Lilly/Elanco, Iowa Corn Growers Association, Iowa Pork Producers Association, Illinois Corn Marketing Board, Illinois Pork Producers Association, Kansas Corn Commission, Kansas Pork Association, Lucta USA, Minnesota Pork Board, Missouri Pork Producers Association, Monsanto, Mississippi Pork Producers Association, Montana Pork Producers Council, National Corn Growers Association, North Carolina Pork Council, Inc., National Pork Board, Nebraska Pork Producers Association, Inc., Ohio Pork Producers Council, Pioneer Hi-Bred International, Inc., Utah Pork Producers Association and the Wisconsin Pork Association.

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 in the experiment. Sixteen of the growing pigs and 16 of the finishing pigs were harvested at the start of the experiment to measure the initial body composition and the total energy concentration in the pigs. The remaining pigs were allotted to diets containing DDGS-CV, DDGS-BPX, or HP-DDG. Growing pigs were fed these diets for four weeks and finishing pigs were fed the diets for five weeks. At the end of the feeding period, all pigs were harvested and the body composition and the concentration of energy in the body were measured. By subtracting the amount of energy in the body at he start of the experiment, the energy retention during the experimental period could be calculated. By dividing this amount of energy by the total feed intake of the pigs during the experimental period, the amount of NE in each of the three ingredients could be calculated.

Results showed that for both growing and finishing pigs, growth performance were unaffected by dietary treatments. In growing pigs, no differences were observed in 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 the DDGS-BPX diet or the HP-DDG diet. 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) and HP-DDG (2,291 kcal/kg). The average NE of DDGS-CV, DDGS-BPX, and HP-DDG was greater ($P < 0.05$) in finishing pigs than in growing pigs.

In conclusion, results of this research suggest that the NE for DDGS-CV, DDGS-BPX, and HP DDG is 1,665, 1,596, and 1,783 kcal/kg, respectively, for growing pigs, and 2,718, 2,065, and 2,291 kcal/kg, respectively, for finishing pigs.

The NE of DDGS is greater in finishing pigs than in growing pigs, and the greater the concentration of fat is in DDGS, the greater is the NE.

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SCIENTIFIC ABSTRACT:

An experiment was conducted to determine the NE 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 52 growing pigs (initial BW: 20.8 ± 2.06 kg BW) and 52 finishing pigs (initial BW: 87.2 ± 9.77 kg BW) were allotted within each stage of growth to 6 treatment groups based on BW. There were 8 replicate pigs in 2 treatment groups and 9 pigs in the remaining 4 treatment groups at each stage of growth. The 2 treatments with 8 pigs at each stage of growth were used as the initial slaughter group (ISG) and all pigs in these groups were harvested at the initiation of the experiment. Pigs in the remaining 4 treatment groups at each stage of growth 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 GE. The NE values for DDGS-CV, DDGS-BPX and HP-DDG were calculated using the difference procedure by subtracting the contribution from the basal diet to the NE of the treatment diets. Results showed that for both growing and finishing pigs, growth performance was unaffected by dietary treatments. In growing pigs, no differences were observed in 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 the basal diet, the DDGS-BPX diet or the HP-DDG diet. 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) and HP-DDG (2,291 kcal/kg). No interactions were observed between ingredient and stage of growth, but the NE of DDGS-CV, DDGS-BPX and HP-DDG was greater ($P < 0.05$) in finishing pigs than in growing pigs. The results suggest that the NE values of DDGS-CV, DDGS-BPX and HP-DDG may vary according to the growth stage, but DDGS-CV contains more NE than DDGS-BPX and HP-DDG.

INTRODUCTION

Distillers dried grains with solubles (**DDGS**) and high protein distillers dried grains (**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, 1993), and therefore, an accurate estimation of the energy value of DDGS and HP-DDG is necessary.

In North America, energy is usually expressed as DE or ME. However, DE and ME systems tend to overestimate the energy value of fibrous or high protein feedstuffs and underestimate ingredients that have high concentrations of starch and fat (Noblet et al., 1994a). 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., 1994a).

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 in HP-DDG than in corn.

The NE of soybean hulls, wheat middlings, corn, soybean oil, and choice white grease was recently measured (Stewart, 2007; Kil, 2008). However, values for NE in DDGS and in 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.

OBJECTIVES

The objective of this experiment was to determine the NE in 2 sources of DDGS and in 1 source of 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 line 337 sires mated to C-22 females (Pig Improvement Company, Hendersonville, TN) were obtained from the University of Illinois Swine Research Center. The average initial BW of the pigs 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 allotted to 8 outcome groups of 6 barrows and 1 outcome group of 4 barrows according to BW. Within each outcome group, pigs were randomly allotted to 6 treatment groups for each stage of growth 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 (36 pigs) within each stage of growth were assigned to 4 dietary treatments and all pigs in these 4 treatment groups were harvested at the conclusion of the experiment. The experimental period was 28 d for growing pigs and 35 d for finishing pigs.

Pigs were housed individually in 0.9 x 1.8 m pens in an environmentally controlled building. Pens were equipped with a fully-slatted concrete floor, a feeder and a bowl shaped nipple 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) obtained from Poet Nutrition (Sioux Falls, SD) and 1 source of high protein distillers dried grains (HP-DDG) obtained from Poet Nutrition (Sioux Falls, SD), were used and analyzed for chemical composition (Table 1). The same batch of these ingredients was used for both growing and finishing pigs. Four diets at each stage of growth were formulated (Table 2). The basal diet contained corn, SBM, and soybean oil. 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 were pooled at the end of the experiment for each phase. A sample of each of the ingredients was collected at the feed mill before the diets were mixed at the initiation of the experiment. 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. At the end of the experiment, ADG, ADFI, and G:F for each pig were calculated and summarized within treatment and stage of growth.

On d 6 of each week, pens were scraped clean of all fecal material. On d 7, fresh fecal samples were collected from each pig by grab sampling. The collected fecal samples were pooled within pig at the end of the experiment, lyophilized, and finely ground before chemical analyses.

The comparative slaughter procedure was used to estimate the retention of energy, protein, and lipids in pigs fed the experimental diets (de Goey and Ewan, 1975). Pigs were weighed on the last day of the experiment and feed was withheld for 16 h. At harvest, all pigs were weighed again, and euthanized by captive-bolt stunning followed by exanguination. Care was taken to ensure that all blood was collected from each pig, and total blood weight was recorded. The blood sample was collected in 150 mL bottles containing EDTA as an anticoagulant and stored at -20°C until analyzed. Blood samples were freeze dried and ground prior to sample analysis. The carcass was split down the midline from the groin to the chest cavity and the viscera were removed. The carcass, the viscera, and the blood were collected, weighed, and processed separately.

Hot carcass weights for all pigs were recorded using a Toledo scale (Worthington, OH) mounted on the carcass trail, and stored in a cooler at 4°C for 16 h. Prior to grinding, a chilled carcass weight was recorded, and the carcasses were cut into pieces using a bone saw to split the carcass into sides and a hand saw to split medially, in order to fit into the grinding apparatus (Autio Company, Astoria, OR) and to ensure an adequate mixing of the skull contents. Carcasses were ground twice using a 12 mm die for growing pigs and an 18 mm die for finishing pigs. During the second grind, the carcass was split off into equal barrels. One of 2 barrel barrels was chosen randomly, and the contents were mixed in a mixer

(Keebler Company, Chicago, IL) to ensure even distribution and to facilitate sampling of the carcass. After 1 min of mixing, approximately 8 kg of carcass were collected and stored at -20°C. The frozen carcass samples were then thawed at 4°C for 16 h and cut into half inch slices using a band saw (Hobart Company, Troy, OH). The carcass slices were ground twice through a meat grinder (Lasar Manufacturing Company Incorporated, Los Angeles, CA) using a 2 mm die and sub samples for chemical analysis were collected. The carcass sample used for analysis was then lyophilized to a constant weight and finely ground for analysis. The remaining sample was kept as extra sample.

The digestive tracts were separated from the other organs and flushed with water to remove the digesta. Weights of body organs including liver, lungs, heart, kidney and spleen were recorded. The emptied gastrointestinal tract was patted dry and then weighed. The body organs and the empty gastrointestinal tract were then stored at 4°C overnight. The following day, the viscera including the gastrointestinal tract and the internal organs, were ground in a Butcher Boy meat mincer using a 10 mm die followed by a second grind using a 2 mm die. Ground viscera were mixed and sub samples were collected and stored at -20°C. After thawing for 16 h at 4°C, the viscera samples were ground using a food processor (Proctor Silex, Hamilton Beach, CA) and then lyophilized and ground again prior to chemical analysis. Blood samples were also lyophilized to a constant weight and finely ground prior to chemical analyses.

Chemical Analyses

Samples were analyzed in duplicates and analyses were repeated if results from the duplicate samples varied more than 5% from the mean. The DM of diets, feed ingredients and fecal samples was determined by oven drying at 135°C for 2 h (method 930.15; AOAC, 2005). The DM of body components including carcass, viscera and blood was determined after freezing drying to a constant weight. The GE of diets and ingredients, feces, and body components were determined with an adiabatic bomb calorimeter (model 6300, Parr Instruments, Moline, IL) using benzoic acid as a calibration standard. The N concentration of diets, ingredients, and body components was determined by 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 lipids of diets, ingredients, and body components was determined using the petroleum ether extraction procedure (method 2003.06; AOAC, 2005) using a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). The concentration of total lipids in diets, ingredients, and feces was also determined after acid hydrolysis using 3 N hydrochloric acid followed by petroleum ether extraction (method 996.01;AOAC, 2005).

Calculations

Data for ADFI, ADG, and G:F were calculated and then summarized within each treatment and within each stage of growth. 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 then 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 ISG (Oresanya et al., 2008). The following equation was used for this calculation:

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

where TBi is the total body quantity of energy, protein or lipids at the start of the experiment, LW is the initial live weight (kg) of the experimental pigs, and ISGi is the average concentration (mcal/kg) of energy, protein, or lipids that was calculated from the pigs in the ISG. Energy retention was also calculated by multipling protein gain (g) and lipid gain (g) by 5.66 and 9.46 kcal/g for protein and lipids, 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 of the basal diet from the NE of the diets containing DDGS-BPX, DDGS-CV, and HP-DDG (de Goey and Ewan, 1975).

Statistical Analyses

All data from each phase was 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 data were identified as outliers. Diet was a fixed effect and outcome group was a random effect in the model. The difference among treatments were determined using ANOVA, and the means were separated using LS means statement and the PDIFF option with the 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 it 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). In growing pigs, live BW was lower ($P < 0.05$) for pigs fed the DDGS-BPX and DDGS-CV diets than for pigs fed the basal diet (Table 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 (liver, lungs, heart, kidney and spleen) 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, no difference was observed between pigs fed the DDGS-BPX and DDGS-CV diets compared with pigs fed the HP-DDG and basal diets.

In finishing pigs, live BW, hot carcass weight, and chilled carcass weight were not affected by dietary treatments (Table 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 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 HP-DDG diet than 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 and pigs fed the HP-DDG diet (Table 6). The total amount of protein and the 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 and 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 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 initial body energy, final body energy, energy retention, and total operational NE requirement for maintenance was observed (Table 8). Total net energy intake and total feed intake were not affected by dietary treatments. The net energy 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.

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, and 2,171 kcal/kg for the HP-DDG. The NE of DDGS-CV was greater ($P < 0.05$) than the NE of DDGS-BPX diet (2,718 kcal/kg vs. 2,065 kcal/kg). But the NE of HP-DDG (2,291 kcal/kg) was not different from DDGS-CV or DDGS-BPX.

The NE of all diets were greater ($P < 0.001$) for finishing pigs than for growing pigs (Table 9). The NE for DDGS-BPX and HP-DDG were not affected by the stage of growth, but the NE of DDGS-CV was greater ($P < 0.001$) for finishing pigs 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 10). The NE of ingredient was greater ($P < 0.001$) for finishing pigs than for growing pigs, but no differences among ingredients were observed.

DISCUSSION

The growth performance of pigs fed the DDGS and HP DDG diets was not different from the growth performance of pigs fed the control diet. This observation agrees with previous observations showing that inclusion of DDGS and HP DDG in diets fed to growing-finishing pigs will not affect growth performance of the pigs (Cook et al., 2005; DeDecker et al., 2005; Widmer et al., 2008).

The protein gain for growing (149.7 g/d) and finishing (146.5g/d) pigs fed the basal diet is similar to the values reported by Quiniou et al. (1996) who obtained maximum values of protein gain of 151 g/kg for growing and finishing pigs fed ad libitum. The values for protein gain reported by Kil (2008) were, however, greater for growing (161 g/d) and finishing (171 g/d) pigs fed a basal corn soybean meal based diet than the values obtained in this study.

In both growing and finishing pigs, MER and CER values were similar, which confirms that he measured values are accurate. Increased intestinal mass has been reported when high fiber diets are fed to pigs (Kass et al., 1980), but in the present experiment, no effects of DDGS or HP DDG on the dressing percentage were observed. This observation agrees with Hochstetler et al. (1959), who also reported that the dressing percentage was not affected by feeding high fiber diets containing cellulose, oat bran, or alfalfa diets. Also, Gargallo and Zimmerman (1981) reported that different levels of dietary sunflower hulls did not have an effect on the weight of empty intestines.

In growing and finishing pigs, similar values for NE of diets were obtained for pigs fed the basal diet and pigs fed the DDGS-BPX diet, DDGS-CV diet, and the HP-DDG diet. This observation agrees with the fact that DE and ME in DDGS and corn are not different (Pedersen et al., 2007). It has been suggested that because DDGS is a high fiber feedstuff, lower NE in DDGS than in corn should be expected (Noblet et al., 1994). However, because of the higher lipid content of DDGS-BPX and DDGS-CV than corn, an increased utilization of dietary energy for lipid gain is expected, because dietary lipids have a higher efficiency for lipid deposition than for maintenance (Just et al., 1983; Black, 1995). As a result, the NE of the basal corn-soybean meal diet is similar to that of the diets containing DDGS-BPX and DDGS-CV.

Widmer et al. (2007) reported greater DE and ME values for HP-DDG than for corn. However, the CP content of HP-DDG is greater and the lipid concentration is lower than in corn, which may explain why the NE for HP DDG diet is similar to the NE for the basal diet.

The NE of DDGS-CV, DDGS-BPX, and HP DDG that were obtained in growing pigs was similar to the NE of corn. The values were also similar to the NE value for DDGS (1,673 kcal/kg) obtained by Sauvant et al. (2004). However, the NE of the three ethanol co-products in finishing pigs was greater than the NE of DDGS for sows (1,935 kcal/kg) determined by Sauvant et al. (2004). However, the the DDGS used by Sauvant et al. (2004) studies had lower GE and lipid concentration and higher CP concentration than the DDGS used in the present experiment. Therefore the lower lipid concentration and high CP will negatively affect the NE content of DDGS.

The NE of DDGS-CV for finishing pigs was greater than the NE of DDGS-BPX and HP-DDG, because pigs fed the DDGS-CV diet had greater lipid gain and therefore greater energy retention. The reason for this greater NE value in DDGS-CV may be the greater lipid concentration of DDGS-CV.

In conclusion, the NE value of DDGS-BPX, DDGS-CV, and HP-DDG is greater for finishing than for growing pigs. In the finishing stage, the NE of DDGS-CV is greater than the NE of DDGS-BPX and HP-DDG.

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TABLES

Table 1. Analyzed composition of distillers dried grains with soluble (DDGS) and high protein distillers dried grains (HP-DDG) as fed basis

	Ingredient[1]		
Composition	DDGS-BPX	DDGS-CV	HP-DDG[1]
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

[1] 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).

[2] Acid ether extract = acid hydrolyzed ether extract after hydrolysis with 3 N HCL.

Table 2. Composition of experimental diets[1] (as fed basis)

	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
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
Antibiotic	0.15	0.10	0.10	0.10	-	-	-	-
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Energy and nutrients[2]								
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
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[3], %	4.90	7.85	8.10	5.47	3.66	6.84	7.38	5.19
ADF, %	3.37	12.74	12.74	4.97	3.13	12.57	12.57	4.80
NDF, %	8.85	11.09	11.09	11.12	9.15	11.29	11.29	11.32
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] 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.

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

[3] Acid ether extract = acid hydrolyzed ether extract after hydrolysis with 3 N HCL.

Table 3. Effects of treatments on growth performance of growing and finishing pigs[1]

	Diet[2]					
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 square 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] 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. Weights of carcass and body components of growing pigs[1]

	Dietary treatment[2]					
	Basal	DDGS-BPX	DDGS-CV	HP-DDG	SEM	*P*-value
Live wt, kg	44.8^{y}	40.5^{x}	41.9^{x}	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
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[3], 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[4], 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, kg	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
Heart / total digesta-free BW	0.50	0.51	0.52	0.50	0.018	0.84
Liver / total organ wt	49.0	46.9	46.3	47.3	1.07	0.26
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] 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 5. Weights of carcass and body components of finishing pigs[1]

	Dietary treatment[2]					
	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
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[3], 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[4], 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
Heart / total digesta-free BW	0.39	0.38	0.40	0.39	0.019	0.92
Liver / total organ wt	41.5	41.6	41.6	41.9	1.51	1.00
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] 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 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]					
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
Lipid gain, g/d	-	158.8	133.1	130.3	147.1	13.27	0.38
Lipid:protein,[4] 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] 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] Lipid:protein = the ratio of daily lipid gain to daily protein gain.

[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 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]

Item	ISG[2]	Dietary treatment[3]				SEM	*P*-value
		Basal	DDGS-BPX	DDGS-CV	HP-DDG		
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
Lipid gain, g/d	-	312.2^{xy}	219.5^{x}	345.6^{y}	252.6^{xy}	30.06	0.02
Lipid:protein,[4] 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] 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] Lipid:protein = the ratio of daily lipid gain to daily protein gain.

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

Item	Dietary treatment[2]				SEM	*P*-value
	Basal	DDGS-BPX	DDGS-CV	HP-DDG		
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$_m$,[3] 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,[4] 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
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$_{m,}$[3] 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,[4] 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] 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.

[3] 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).

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

Table 9. Comparison of NE values for diets and ingredients between growing and finishing pigs[1]

	NE, kcal/kg			
Item	Growing	Finishing	SEM	*P*-value
Diet[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
Ingredient				
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.

Table 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				*P*-value[3]	
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] *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.