RESEARCH REPORT
ANIMAL SCIENCE

Title: Phosphorus digestibility and concentration of digestible and metabolizable energy in corn, corn co-products, and bakery meal fed to growing pigs – **NPB #11-168**

Investigator: Hans H. Stein

Institution: University of Illinois.

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INDUSTRY SUMMARY

The main aim of this research was to determine P digestibility and concentration of digestible and metabolizable energy in corn, corn co-products, and bakery meal fed to growing pigs. It was also the purpose to determine the effect of addition of phytase on P digestibility. Swine producers may take advantage of the results from this research because the cost of most traditional feed ingredients has increased in recent years and the current data provide values for DE and ME and the digestibility of P in alternative ingredients. If DDGS, hominy feed, or bakery meal rather than corn is used in diets for pigs, the ME concentration of the diet will not change and if corn gluten meal is used, the ME will increase. However, if corn gluten feed or corn germ meal are used, the ME in the diet will be reduced, which may result in a reduction in ADG or in an increased feed conversion rate. Use of corn gluten meal, DDGS, or corn gluten feed will also increase the addition of digestible P in the diet, and the need for inorganic P will be reduced, which will also reduce the cost of the diet. Likewise, if microbial phytase is used in diets containing corn, corn-products, or bakery meal, the digestibility of P will increase and the excretion of P will decrease. Thus, the present data will allow swine producers to formulate diets containing several alternative ingredients and possibly reduce diet costs. Results can be implemented

immediately without requiring producers to invest in additional technology.

SCIENTIFIC ABSTRACT:

Two experiments were conducted to determine the standardized total tract digestibility (STTD) of P and the concentration of ME in corn, hominy feed, bakery meal, distillers dried grains with solubles (DDGS), corn gluten meal, corn gluten feed, and corn germ meal fed to growing pigs. In Exp. 1, 84 barrows (BW: 13.7 ± 2.3 kg) were placed in metabolism cages and allotted to a randomized complete block design with 14 diets and 6 pigs per diet. Fourteen diets were formulated to contain corn, hominy feed, bakery meal, DDGS, corn gluten meal, corn gluten feed, or corn germ meal and either 0 or 500 units of microbial phytase. The STTD of P was greater ($P < 0.01$) in DDGS, corn gluten meal, and corn gluten feed than in corn, hominy feed, bakery meal, and corn germ meal, and the STTD of P was also greater ($P < 0.01$) in bakery meal than in corn and hominy feed. Addition of phytase increased ($P < 0.05$) the STTD of P in corn, hominy feed, bakery meal, and corn germ meal, but not in corn gluten meal, corn gluten feed, and DDGS. In Exp. 2, 56 barrows (BW: 14.6 ± 2.2 kg) were placed in metabolism cages and allotted to a randomized complete block design with 7 diets and 8 pigs per diet. Three diets based on corn, hominy feed, or bakery meal and 4 diets containing corn and DDGS, corn gluten feed, corn gluten meal, or corn germ meal were formulated. The concentration of ME was 3,891, 3,675, 3,655, 3,694, 4,400, 3,169, and 3,150 kcal/kg DM in corn, hominy feed, bakery meal, DDGS, corn gluten meal, corn gluten feed, and corn germ meal, respectively. The ME in corn was greater ($P < 0.01$) than in hominy feed, bakery meal, corn gluten feed, and corn germ meal, but less ($P < 0.01$) than in corn gluten meal. In conclusion, DDGS, corn gluten meal, and corn gluten feed have a greater STTD of P than corn, hominy feed, bakery meal, and corn germ meal, but phytase can be included in diets containing corn, hominy feed, bakery meal and corn germ meal to improve P digestibility. The ME was greater in corn gluten meal than in bakery meal, corn, and corn co-products.

Key words: bakery meal, corn, corn co-products, energy, phosphorus digestibility, pig

INTRODUCTION:

Many co-products from the human food industry may be used in diets fed to pigs and poultry. Such ingredients include hominy feed, bakery meal, corn gluten meal, corn gluten feed, and corn germ meal and effects of some of these ingredients on pig growth performance have been reported (Mahan and Newton, 1993; Kwak and Kang, 2006). The apparent and standardized ileal digestibility of CP and AA in hominy feed, bakery meal, corn gluten meal, corn gluten feed, and corn germ meal have also been reported (Almeida et al., 2011). However, there is a lack of data for the DE and ME in these ingredients and there are no comparative data for the DE and ME in these ingredients and corn and distiller dried grains with solubles (**DDGS**).

Much of the P in plant ingredients is bound to phytate (Eeckhout and De Paepe, 1994), which decreases P digestibility. However, addition of microbial phytase to corn and soybean meal (**SBM**) increases P digestibility, but that is not always the case when microbial phytase is added to DDGS (Almeida and Stein, 2010; 2012) because fermentation reduces the concentration of phytate in feed ingredients (Almeida and Stein, 2010; Rojas and Stein, 2012). There are, however, no data on the effect of microbial phytase when added to corn gluten meal, corn gluten feed, corn germ meal, hominy feed, and bakery meal, and there are no comparative data for P-digestibility among these ingredients. Therefore, the first objective of this work was to determine the concentration of DE and ME in hominy feed, bakery meal, corn gluten meal, corn gluten feed, and corn germ meal and to compare these values with values obtained for corn and DDGS. The second objective was to determine the standardized total tract digestibility (**STTD**) of P and the effect of microbial phytase on the STTD of P in these ingredients.

STATED OBJECTIVES FROM ORIGINAL PROPOSAL:

The objective of this research is to determine the digestibility of energy and phosphorus (without and with microbial phytase) in bakery meal and corn co-products and to compare these values to the digestibility of energy and P in corn and distillers dried grains with solubles (DDGS). At the conclusion of this research, values

for the DE and ME and the digestibility of phosphorus without and with phytase will be available to the feed and swine industries. It will then be possible to formulate diets containing bakery meal, hominy feed, and other corn co-products based on values for digestible energy and nutrients.

MATERIALS AND METHODS:

Two experiments were conducted, and the Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocols for both experiments. Pigs used in the experiments were the offspring of G-performer boars mated to F-25 females (Genetiporc, Alexandria, MN). Ingredients used in the experiments included corn, hominy feed, bakery meal, DDGS, corn gluten meal, corn gluten feed, and corn germ meal (Table 1). The same batches of these ingredients were used in both experiments. The hominy feed was procured from Agricolor Inc., Marion, IN, the bakery meal was sourced from Custom Trading & Blending, Terre Haute, IN, and the DDGS was sourced from Big Rivers Resources, West Burlington, IA. Corn gluten meal, corn gluten feed, and corn germ meal were obtained from Archer Daniels Midland, Decatur, IL. The corn was a commercial hybrid of yellow dent corn that was sourced from the University of Illinois Feed Mill (Urbana, IL).

Exp. 1: Phosphorus Digestibility

Diets, Animals, and Experimental Design. Experiment 1 was designed to determine apparent total tract digestibility (**ATTD**) and STTD of P in hominy feed, bakery meal, DDGS, corn gluten meal, corn gluten feed, and corn germ meal, and to compare these values to the values obtained for corn. Eighty-four barrows (initial BW: 13.7 ± 2.3 kg) were placed in metabolism cages in a randomized complete block design with 14 diets and 6 replicate pigs per diet. Three diets were based on corn, hominy feed, or bakery meal and no inorganic P was included in these diets (Table 2). Four additional diets were formulated by mixing cornstarch and sugar with corn gluten meal, corn gluten feed, corn germ meal, or DDGS and the corn co-products were the sole sources of P in these diets. Seven additional diets that were similar to the initial 7 diets with the exception that 500 units per kilogram of microbial phytase (Optiphos 2000, Enzyvia, Sheridan, IN) were added to each diet were also

formulated. Vitamins and all minerals except P were included in the diets according to current requirements (NRC, 2012).

Feeding and Sample Collection. Feed was supplied in a daily amount of 2.5 times the maintenance energy requirement (i.e., 106 kcal of ME/kg of $BW^{0.75}$; NRC, 1998) of the smallest pig in each replicate and divided into 2 equal meals that were fed at 0800 and 1700 h. Water was available at all times.

Pigs were fed experimental diets for 12 d. The initial 5 d were considered an adaptation period to the diet. Fecal markers were fed on d 6 (chromic oxide) and on d 11, (ferric oxide) and fecal collections were initiated when chromic oxide appeared in the feces and ceased when ferric oxide appeared (Adeola, 2001). Feces were collected twice daily and stored at -20ºC immediately after collection.

Chemical Analyses. All samples were analyzed in duplicate. Fecal samples were dried at 65ºC in a forced-air oven and ground through a 1-mm screen in a Wiley mill (Model 4; Thomas Scientific, Swedesboro, NJ) before analysis. Diets, ingredients, and fecal samples were analyzed for DM (Method 930.15; AOAC Int., 2007). Phosphorus and Ca were analyzed in all samples by the inductively coupled plasma spectroscopy procedure (Method 985.01 A, B, and C; AOAC, Int., 2007) after wet ash sample preparation [Method 975.03 B(b); AOAC Int., 2007]. Diets and ingredients were also analyzed for ADF (Method 973.18; AOAC Int., 2007), NDF (Holst, 1973), ash (Method 942.05; AOAC Int., 2007), GE by adiabatic bomb calorimetry (Model 6300 Parr Instruments, Moline, IL), for phytase activity (Phytex Method, Version 1; Eurofins, Des Moines, IA), and phytate concentration (Ellis et al., 1977). All ingredients were analyzed for AA on a Hitachi Amino Acid Analyzer, Model No. L8800 (Hitachi High Technologies America, Inc; Pleasanton, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard [Method 982.30 E(a, b, c); AOAC Int., 2007]. Crude protein was also analyzed in all ingredients by combustion (Method 990.03; AOAC Int., 2007) on an Elementar Rapid N-cube protein/nitrogen apparatus (Elementar Americas Inc., Mt. Laurel, NJ) and acid hydrolyzed ether extraction (**AEE**) was determined by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction using petroleum ether (Method 2003.06, AOAC Int., 2007) on a Soxtec 2050

automated analyzer (FOSS North America, Eden Prairie, MN). Ingredients were also analyzed for total starch using the glucoamylase procedure (Method 979.10; AOAC Int., 2007), and monosaccharides were analyzed as described by Cervantes-Pahm and Stein (2010).

Calculations and Statistical Analysis. The apparent total tract digestibility (**ATTD**) of P was calculated for each ingredient using the direct procedure (Almeida and Stein, 2010). The STTD of P was calculated for each ingredient by correcting the ATTD of P for the endogenous P loss, which was assumed to be 200 mg/kg DMI (Stein, 2011). The concentration of non-phytate and phytate bound P in corn and co-products were calculated as previously described (Rojas and Stein, 2012).

Data were analyzed using the MIXED Procedure (SAS Inst. Inc., Cary, NC). Homogeneity of the variances among treatments was confirmed using the UNIVARIATE procedure and this procedure was also used to test for outliers, but no outliers were identified. The fixed effect was phytase and pigs and replicate were considered random effects. The LSMeans statement was used to calculate treatment means, and the PDIFF option was used to separate means if differences were detected. The pig was the experimental unit for all analyses and an alpha level of 0.05 was used to assess significance among means.

Exp. 2: Energy Digestibility

Diets, Animals, and Experimental Design. Experiment 2 was designed to determine ATTD of GE and the concentration of DE and ME in corn, hominy feed, bakery meal, DDGS, corn gluten meal, corn gluten feed, and corn germ meal. Fifty six barrows (initial BW: 14.6 ± 2.2 kg) were placed in metabolism cages equipped with a feeder and a nipple drinker in a randomized complete block design with 7 diets and 8 replicate pigs per diet. A corn-based diet and 4 diets containing corn and DDGS, corn gluten feed, corn gluten meal, or corn germ meal were formulated (Table 3). Two additional diets that contained hominy feed or bakery meal as the only source of energy were also formulated. Vitamins and minerals were included in the diets to meet or exceed the requirements for weanling pigs (NRC, 2012).

Feeding and Sample Collection. Feed was supplied in a daily amount of 3 times the maintenance energy requirement (i.e., 106 kcal of ME/kg of $BW^{0.75}$; NRC, 1998) of the smallest pig in each replicate and divided into 2 equal meals that were provided at 0800 and 1700 h. Water was available at all times.

Pigs were fed experimental diets for 12 d. Feces were collected twice daily as explained for Exp. 1 and stored at -20ºC immediately after collection. Urine was also collected and urine collections started on d 6 at 1700 h and ceased on d 11 at 1700 h. Urine buckets were placed under the metabolism cages to permit total collection and buckets were emptied in the morning and afternoon and a preservative of 50 mL of sulfuric acid was added to each bucket when they were emptied. The collected urine was weighed and a 10% subsample was stored at -20ºC.

Chemical Analysis. Fecal samples were dried as described for Exp. 1. After completing sample collections, urine samples were thawed and mixed within animal and diet, and a subsample was lyophilized before energy analysis as previously described (Kim et al., 2009). Diets were analyzed for DM, CP, ADF, and NDF, as described for Exp. 1, and diets and fecal samples were analyzed for GE as described for Exp. 1. The GE in urine samples were analyzed as described by Kim et al. (2009).

Calculations and Statistical Analysis. The ATTD of GE was calculated as previously described (Stein et al., 2004). The amount of energy lost in the feces and urine was calculated and the quantities of DE and ME in each of the 7 diets were calculated as well (Stein et al., 2004). For corn, hominy feed, and bakery meal, DE and ME values were calculated for each ingredient by dividing the DE or ME of the diet by the inclusion rate of the ingredient. The contribution of DE and ME from corn to the diets containing corn gluten meal, corn gluten feed, corn germ meal, or DDGS was subtracted from the DE and ME of these diets, and the DE and ME in each ingredient were then calculated by difference (Adeola, 2001). Data were analyzed as described for Exp.1.

RESULTS:

Exp. 1: Phosphorus Digestibility

Daily feed intake (DM-basis) was not different among pigs fed the diets without phytase or with phytase (Table 4). Phytase did not influence the daily P-intake of pigs fed the diets containing bakery meal, DDGS, corn gluten meal, or corn gluten feed, but daily P intake was greater ($P < 0.01$) for pigs fed the hominy feed and corn germ meal diets with phytase than pigs fed the same diets without addition of phytase (ingredient × phytase interaction; $P < 0.01$). There were no differences in fecal P excretion or toal daily P excretion between pigs fed the DDGS and corn gluten feed diets without or with phytase, but for all other ingredients, the P concentration in feces was less ($P < 0.01$) for pigs fed diets containing phytase than from pigs fed the diets without phytase (interaction, $P < 0.01$). Pigs fed the corn and corn gluten meal diets either without phytase or with phytase had the least ($P < 0.01$) daily absorption of P compared with the other diets.

The ATTD of P was greater ($P < 0.01$) in DDGS and corn gluten meal than in corn, hominy feed, and bakery meal, but less ($P < 0.01$) than in corn gluten feed. The addition of phytase increased ($P < 0.01$) the ATTD of P in corn, hominy feed, bakery meal, and corn germ meal, but ATTD of P was not improved by addition of phytase to DDGS, corn gluten meal, and corn gluten feed (ingredient × phytase interaction, $P < 0.05$). There were no differences in the basal EPL of pigs fed the experimental diets. The STTD of P in corn gluten meal was greater ($P < 0.01$) than in corn, hominy feed, bakery meal, and corn germ meal, but not different from DDGS and corn gluten feed. When phytase was added to the diet there was an increased ($P < 0.01$) STTD of P in corn, hominy feed, bakery meal, corn gluten meal, and corn germ meal, but not in DDGS and corn gluten feed (ingredient × phytase interaction, $P < 0.05$).

Exp. 2: Energy Digestibility

Gross energy intake was greater ($P < 0.01$) for pigs fed the hominy feed or DDGS diets than for pigs fed the other diets, but there were no differences in GE intake among pigs fed diets containing corn, bakery meal, corn gluten meal, corn gluten feed, or corn germ meal (Table 5). Pigs fed the corn, bakery meal, or corn gluten

meal diets had less ($P < 0.01$) fecal excretion of GE than pigs fed the hominy feed, DDGS, corn gluten feed, or corn germ meal diets. The urine excretion of GE was greater ($P < 0.01$) for pigs fed the bakery meal diet than for pigs fed the other diets and pigs fed the diet containing corn gluten meal had greater ($P < 0.01$) urine excretion than pigs fed the diets containing corn, hominy feed or corn germ meal. The ATTD of GE was greater ($P < 0.01$) for pigs fed the corn, bakery meal, or corn gluten meal diets than for pigs fed the other diets, but the ATTD of GE was less ($P < 0.01$) for pigs fed the diet containing hominy feed than for pigs fed the diets containing DDGS or corn germ meal. The concentration of DE was greater in corn, bakery meal, and DDGS diets than in hominy feed, corn gluten feed, and corn germ meal diets, but less ($P < 0.01$) than in the corn gluten meal diet. The DE in the hominy feed diet was also greater ($P < 0.01$) than in the diets containing corn gluten feed or corn gluten meal. The ME of the corn diet was less ($P < 0.01$) than the ME of the corn gluten meal diet, but greater ($P < 0.01$) than in hominy feed, bakery meal, corn gluten feed, or corn germ meal diets. The ME of the diets containing hominy feed, bakery meal, or DDGS was also greater ($P < 0.05$) than the ME in the diets containing corn gluten feed or corn germ meal.

The ATTD of GE was greater ($P < 0.01$) in corn gluten meal than in all other ingredients except corn and the ATTD of GE in corn and bakery meal was greater ($P < 0.01$) than in hominy feed, DDGS, corn gluten feed, and corn germ meal. The ATTD of GE in hominy feed was also greater ($P < 0.01$) than in corn gluten feed and corn germ meal. The DE (as-fed and DM basis) was greater in corn gluten meal than in all other ingredients. The DE in DDGS and in corn (DM basis) was greater ($P < 0.01$) than in hominy feed, corn gluten feed, and corn germ meal, and the DE in hominy feed and bakery meal was greater ($P < 0.01$) than in corn gluten feed and corn germ meal. The ME (as-fed and DM basis) was also greater ($P < 0.01$) in corn gluten meal than in all other ingredients. The ME (DM basis) was greater ($P < 0.01$) in corn than in hominy feed, bakery meal, corn gluten feed, and corn germ meal, but not different from the ME in DDGS. The ME in hominy feed, bakery meal, and DDGS was also greater ($P < 0.01$) than in corn gluten feed and corn germ meal.

DISCUSSION:

Corn can be used in the animal feed industry, in the dry milling industry, the corn wet milling industry, or in the dry grind corn processing industry. Products produced from corn include high energy feed, flaking grits, starch, corn oil, and ethanol (Gulati et al., 1996; Nebraska Corn Board, 2005; Serna-Saldivar, 2010a). As the main products are produced, corn co-products are also produced. These co-products include hominy feed from the dry milling industry, DDGS from the dry grind industry, corn gluten meal and corn gluten feed from the corn wet milling industry, and corn germ meal from either corn wet milling or corn dry grind industries (NRC, 2012). Bakery meal is an ingredient made up of unsold and unsalable products from bakeries and food processing plants (Champe and Church, 1980; Arosemena et al., 1995) and is widely used in the feed industry.

I. Exp. 1: Phosphorus Digestibility

The concentration of P in corn, DDGS, and corn gluten feed concur with the values reported by NRC (1998). Phosphorus concentration in hominy feed, bakery meal, and corn gluten meal is slightly greater than the values reported by Arosemena et al. (1995) and NRC (1998), but they are in agreement with values reported by Sauvant et al. (2004).

The phytate that is present in feed ingredients of plant origin such as corn (Selle and Ravindran, 2008) and SBM (Eeckhout and De Paepe, 1994) binds P and the P, therefore, becomes less digestible (Selle and Ravindran, 2008). The Phytate concentration in corn that was determined in this expriment is in agreement with the value reported by Almeida and Stein (2012), but the phytate concentration in DDGS is slightly less than the value reported by Almeida and Stein (2012). This variation may be due to variability among ethanol plants in processing, but it is also possible that microbial phytase was included in the enzyme mixture used in the ethanol plant that produced the DDGS because it is estimated that approximately 25% of all ethanol plants in the U.S. use an enzyme mixture that contains phytase. The phytate concentration in corn gluten feed is slightly greater than the value reported by Eeckhout and De Paepe. 1994). This is probably due to differences in processing used to produce corn gluten feed. We are not aware of other publications where values for the concentration of

phytate have been reported for hominy feed, bakery meal, corn gluten meal, and corn germ meal. However, the low phytate concentration in corn gluten feed indicates that most of the phytate was degraded during processing of this ingredient.

The STTD of P in corn and in DDGS concurs with previous values (Pedersen et al., 2007; Almeida and Stein, 2010; 2012). The fact that the responses to microbial phytase was much greater in corn than in DDGS is also in agreement with previous data (Almeida and Stein, 2010; 2012) and is likely a result of the greater concentration of phytate in corn than in DDGS. The STTD of P in corn germ meal is greater than in corn germ (Widmer et al., 2007), which is likely a result of the fact that the corn germ meal used in this experiment was from the wet milling industry, whereas the corn germ used by Widmer et al (2007) originated from the dry grind industry.

The observation that the STTD of P was relatively low in corn and hominy feed, intermediate in corn germ meal, and high in DDGS, corn gluten meal, and corn gluten feed is likely a result of the differences in the processing these ingredients have undergone. Corn and hominy feed were not fermented or steeped, and phytate was, therefore, not degraded, which resulted in the low digestibility of P in these ingredients. In contrast DDGS is fermented and corn gluten meal goes through steeping during production. Corn gluten feed consists of several streams from the wet milling process including streams that have been steeped or fermented and corn extractives are also added to corn gluten feed. Fermentation and steeping hydrolyzes much of the phytate, which results in a low proportion of P being bound in phytate and a high digestibility of P (Carlson and Poulsen, 2003; Lyberg et al., 2006; Rojas and Stein, 2012). It is, therefore, likely that these differences in processing are the reasons for the greater values for STTD if DDGS, corn gluten meal, and corn gluten feed compared with corn and hominy feed. The observation that microbial phytase had a much greater effect on improving the STTD of P in corn and hominy feed than in DDGS, and that no effect was observed for corn gluten meal and corn gluten feed is a result of the greater proportion of P being bound to phytate in these ingredients. Therefore, the effect of phytase changes according to the amount of phytate present in the feed ingredient. It appears that there is no or very limited effect of addition of phytase to ingredients in which less than 25% of P is bound to phytate. This is likely because there is not enough substrate to be hydrolyzed by microbial phytase. The fact that the STTD of P

in corn germ meal was intermediate between the STTD in corn and the fermented or steeped co-products indicate that the time of steeping used in the production of corn germ meal is less than that used for corn gluten meal or corn gluten feed. Results of the phytate analysis supports this hypothesis and as expected, the effect of microbial phytase on improving the STTD of P in corn germ meal was less than in corn and hominy feed, but greater than in DDGS, corn gluten meal, and corn gluten feed.

The proportion of P that was bound to phytate in bakery meal was less than in corn, which is likely a result of mainly wheat being used in the production of the food products used to produce bakery meal. Wheat contains more non-phytate bound P than corn (Eeckhout and De Paepe. 1994). Bakery meal is produced from human consumption products that have gone through different types of processing such as fermentation, steaming, cooking, or baking (Serna-Saldivar, 2010b), which results in a product with a high nutritional value. However, the mixture of products is bakery meal may change overtime, which may result in some variability among sources of bakery meal (Arosemena et al., 1995). It is also possible that the heat used during processing of bakery meal reduced the concentration of phytate because heat can partly hydrolyze phytate (Martinez-Amezcua and Parsons, 2007). The digestibility of Lys in bakery meal is relatively low indicating that this ingredient is processed at high temperatures (Almeida et al., 2011). Values for STTD of P and effects of microbial phytase have been reported for corn and DDGS (Almeida and Stein, 2010; 2012), but to our knowledge no values for the STTD of P in bakery meal, hominy feed, corn gluten meal, corn gluten feed, or corn germ meal have been reported and no effects of microbial phytase on the STTD of P in these ingredients have been published. However, data from this experiment indicate that effects of microbial phytase may be predicted from the concentration of phytate in the ingredients.

Exp. 2: Energy Digestibility

The ATTD of GE and the concentration of DE and ME in corn and DDGS concur with values published by NRC (1998), Pedersen et al. (2007), Stein et al. (2008; 2009). The greater concentration of GE and the reduced ATTD of GE in DDGS compared with corn was also reported by Anderson et al. (2012). This observation is likely a result of the high concentration of insoluble fiber in DDGS, which reduces the

digestibility of GE and, therefore, decreases the ME concentration compared with the ME in corn (Urriola et al., 2010). It has also been reported that the digestibility of lipids in DDGS is relatively low, which also contributes to a low digestibility of GE (Kim et al., 2012).

The concentration of DE and ME in hominy feed is in close agreement with values reported by NRC (1998). The reason of the slightly reduced concentration of DE and ME in hominy feed compared with corn is that hominy feed contains more NDF and less starch than corn and the ATTD of GE in hominy feed is, therefore, less than in corn. A similar observation was reported by Stanley and Ewan (1982).

The DE and ME in corn gluten meal are in agreement with data reported by Anderson et al. (2012). The greater concentration of DE and ME in corn gluten meal than in corn is also in agreement with data reported by Young et al. (1977) and is mainly a result of the greater concentration of CP and the reduced concentration of fiber in corn gluten meal compared with corn (Stock et al., 2000). The fact that the concentration of GE and nutrients as well as the DE and ME in corn gluten feed is similar to that in corn germ meal is in agreement with recently published data (Anderson et al., 2012), although the DE and ME in corn gluten feed in this experiment is slightly greater than the values published by Anderson et al. (2012). The reduced DE and ME in corn gluten feed compared with corn concur with data published by Yen et al. (1994) and Young et al. (1997).

Corn germ meal is produced when the oil is extracted from corn germ (Weber et al., 2010), and as a consequence, the concentration of CP and NDF is greater, but the concentration of fat is less, in corn germ meal than in corn germ (Widmer et al., 2007). The reduced concentration of fat in corn germ meal compared with corn germ is likely the reason for the reduced DE and ME in corn germ meal that were determined in this experiment compared with the values reported for corn germ by Widmer et al. (2007).

The main difference among ingredients with high energy digestibility such as corn, bakery meal, and corn gluten meal compared with ingredients with relatively low energy digestibility such as hominy feed, DDGS, corn gluten feed, and corn germ meal is the concentration of hemicellulose in the ingredients.

The ME in hominy feed, DDGS, corn gluten feed, and corn germ meal was approximately 74, 68, 63, and 67%, respectively, of the GE in these ingredients, whereas the ME of corn was 86% of the GE. The reason

for this difference is likely that hominy feed, DDGS, corn gluten feed, and corn germ meal contain much more fiber than corn, which contributes to a low digestibility of energy. This observation, therefore, indicates that there is an opportunity to obtain more energy from hominy feed, DDGS, corn gluten feed, and corn germ meal if the fermentability of the total dietary fiber can be increased via chemical, physical, or enzymatic treatments.

CONCLUSIONS:

In conclusion, DDGS, corn gluten meal, and corn gluten feed have a greater ATTD and STTD of P than corn, hominy feed, bakery meal, and corn germ meal, but phytase can be included in the diets containing corn, hominy feed, bakery meal, and corn germ meal to improve P digestibility. However, there is no effect of phytase when phytase is included in diets that contain DDGS, corn gluten meal, or corn gluten feed. Corn gluten meal contains more ME than bakery meal and corn co-products, but ME is greater in corn than in hominy feed, bakery meal, corn gluten feed, and corn germ meal, but not different from the ME in DDGS.

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TABLES:

Table 1. Analyzed nutrient composition of corn, hominy feed, bakery meal, distillers dried grains with solubles (DDGS), corn gluten meal, corn gluten feed, and corn germ meal, as-fed basis

	Ingredient						
Item	Corn	Hominy feed	Bakery meal	DDGS	Corn gluten meal	Corn gluten feed	Corn germ meal
GE, kcal/kg	3,924	4,407	4,098	4,769	5,102	4,324	4,184
DM, %	86.74	89.01	88.44	87.55	91.03	85.87	89.41
CP, %	6.68	9.41	8.05	25.43	62.88	23.00	24.76
AEE[1], %	3.40	9.47	7.12	10.36	4.29	4.15	2.06
Ash, %	1.06	3.12	7.12	5.40	4.29	5.71	4.12
Ca, %	0.01	0.01	0.20	0.22	0.01	0.12	0.18
P, %	0.19	0.70	0.48	0.82	0.57	0.87	0.87
Phytate, %	0.55	2.07	0.78	0.43	1.69	0.71	2.06

Phytate bound P, %[2]	0.16	0.58	0.22	0.12	0.48	0.20	0.58
Phytate bound P, % of total P	81.63	83.39	45.83	14.79	83.61	23.01	66.77
Non-phytate P, %[3]	0.03	0.12	0.26	0.70	0.09	0.67	0.29
Non-phytate bound P, % of total P	18.37	16.61	54.18	85.21	16.39	76.99	33.23
Phytase, FTU/kg	< 100	130	330	260	280	340	100
Carbohydrates, %							
Glucose	0.66	1.53	5.03	1.84	0.26	0.37	0.26
Sucrose	1.14	1.93	4.91	0.19	0.14	0.11	0.35
Maltose	0.23	0.57	2.85	2.28	0.15	1.86	0.72
Fructose	0.40	1.32	4.71	0.74	0.50	0.38	0.55
Starch, %	67.29	35.63	38.53	4.56	6.68	9.77	15.93
NDF, %	8.53	21.79	8.19	35.20	10.45	30.88	49.29

ADF, %	2.00	5.51	3.06	10.02	5.23	7.68	11.30
Indispensable AA, %							
Arg	0.33	0.66	0.45	1.13	2.26	0.95	1.55
His	0.19	0.28	0.20	0.67	1.31	0.61	0.64
Ile	0.23	0.32	0.31	0.92	2.60	0.79	0.84
Leu	0.76	0.87	0.65	2.75	10.09	1.86	1.86
Lys	0.22	0.48	0.25	0.75	1.18	1.02	0.94
Met	0.14	0.19	0.12	0.48	1.61	0.32	0.40
Phe	0.31	0.41	0.37	1.24	4.03	0.87	1.04
Thr	0.24	0.37	0.25	0.97	2.03	1.21	0.83
Trp	0.04	0.03	0.08	0.19	0.44	0.16	0.18
Val	0.32	0.48	0.41	1.33	2.89	1.12	1.30
Dispensable AA, %							
Ala	0.47	0.65	0.40	1.62	5.30	1.48	1.38

Asp	0.44	0.73	0.53	1.60	3.85	1.44	1.68
Cys	0.15	0.22	0.16	0.50	1.14	0.43	0.33
Glu	1.13	1.43	1.83	3.04	12.04	2.70	2.84
Gly	0.27	0.49	0.37	0.99	1.84	1.03	1.23
Pro	0.31	0.73	0.63	1.75	5.68	1.61	1.09
Ser	0.30	0.41	0.31	1.07	2.54	0.73	0.80
Tyr	0.21	0.28	0.23	0.91	3.27	0.64	0.67
Total AA	6.06	9.03	7.55	21.91	64.1	18.97	19.6

[1]AEE = acid hydrolyzed ether extract.

[2]Phytate bound P was calculated as 28.2% of phytate (Tran and Sauvant, 2004).

[3]Non-phytate P was calculated as the difference between total P and phytate bound P.

Table 2. Composition of experimental diets without and with phytase[1] containing corn, hominy feed, bakery meal, dried distillers grains with solubles (DDGS), corn gluten meal, corn gluten feed, and corn germ meal, as-fed basis, Exp. 1

Item	Diet						
	Corn	Hominy feed	Bakery meal	DDGS	Corn gluten meal	Corn gluten feed	Corn germ meal
Ingredients, %							
Co-product							
Ground corn	98.57	-	-	-	-	-	-
Co-product	-	98.17	98.37	50.00	30.00	50.00	50.00
Cornstarch	0.03	0.03	0.03	38.20	58.80	38.40	38.40
Sucrose	-	-	-	10.00	10.00	10.00	10.00
Ground limestone	0.70	1.10	0.90	1.10	0.50	0.90	0.90

Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[2]	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Analyzed composition							
Diet without microbial phytase							
DM, %	89.07	89.97	87.70	89.78	93.04	89.33	92.09
Ca, %	0.29	0.61	0.54	0.57	0.27	0.49	0.51
P, %	0.29	0.69	0.48	0.42	0.20	0.45	0.44
Ash, %	2.71	4.52	7.85	3.96	2.08	4.62	3.61
Phytate, %	0.77	2.19	0.84	0.21	0.54	0.36	1.06
Phytase, FTU[2]/kg	210	130	350	170	170	< 100	< 100

Diet with microbial phytase							
DM, %	87.58	89.88	87.19	91.02	93.57	90.09	92.79
Ca, %	0.32	0.52	0.55	0.59	0.26	0.52	0.65
P, %	0.22	0.70	0.48	0.42	0.19	0.46	0.48
Ash, %	2.34	3.28	8.60	4.39	1.44	3.97	3.61
Phytate, %	0.58	2.13	0.85	0.19	0.53	0.37	1.02
Phytase, FTU[2]/kg	560	840	1200	870	740	810	860

[1]Microbial phytase was included at 0.03% in all the diets at expenses of cornstarch. Optiphos 2000 (2000 FTU/g), Enzyvia, Sheridan, IN.

[2]Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and

nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

Table 3. Ingredient composition of experimental diets containing corn, hominy feed, bakery meal, dried distillers grains with solubles (DDGS), corn gluten meal, corn gluten feed, and corn germ meal, as-fed basis, Exp. 2

	Diet						
Item	Corn	Hominy feed	Bakery meal	DDGS	Corn gluten meal	Corn gluten feed	Corn germ meal
Ingredient, %							
Ground corn	97.50	-	-	47.70	77.60	48.00	47.90
Co-product	-	97.90	97.90	50.00	20.00	50.00	50.00
Ground limestone	0.70	1.10	0.90	1.60	0.80	1.30	1.20
Dicalcium phosphate	1.10	0.30	0.70	-	0.90	-	0.20
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix[1]	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Total	100.00	100.00	100.00	100	100	100	100
Analyzed composition							
GE, kcal/kg	3,813	4,229	3,873	4,228	4,032	3,962	3,888
DM, %	87.75	87.50	81.44	86.42	86.38	85.28	88.48
CP, %	6.82	10.18	7.64	17.11	16.46	14.59	15.26
Ash, %	3.09	4.98	8.77	5.63	2.00	4.23	4.42
NDF, %	9.30	22.57	8.34	24.61	7.99	21.30	30.77
ADF, %	2.03	5.51	3.24	6.77	5.18	5.34	6.75
AEE[2], %	2.68	10.13	6.83	6.75	2.40	3.62	2.40

[1]Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and

nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

[2]AEE = acid hydrolyzed ether extract.

Table 4. Effect of microbial phytase[1] on apparent total tract digestibility (ATTD) and standardized total tract digestibility (STTD) of P in corn, hominy feeed, bakery meal, distillers dried grains with soubles (DDGS), corn gluten meal, corn gluten feed and corn germ meal, Exp. 1[2]

Item	Feed intake, g DM/d	P intake, g/d	P in feces, %	P output, g/d	Absorbed P, g/d	ATTD of P, %	Basal EPL,[3] mg/d	STTD of P[4], %
No phytase								
Corn	481	1.6^{g}	2.0^{b}	1.0^{de}	0.6^{h}	36.4^{g}	96.2	42.5^{i}
Hominy feed	467	3.6^{b}	2.1^{b}	2.4^{a}	1.4^{ef}	34.7^{g}	93.4	37.3^{i}
Bakery meal	473	2.6^{cd}	1.9^{b}	1.2^{cd}	1.4^{f}	54.9^{ef}	94.7	58.6^{gh}
DDGS	463	2.2^{f}	0.9^{de}	0.6^{f}	1.6^{def}	72.2^{bc}	92.6	76.5^{bcd}
Corn gluten meal	475	1.0^{h}	2.4^{a}	0.4^{fg}	0.6^{h}	70.6^{bc}	95.0	75.2^{cd}
Corn gluten feed	482	2.4^{cde}	0.7^{ef}	0.5^{fg}	2.0^{abc}	80.7^{a}	96.3	84.6^{ab}

Corn germ meal	489	2.3^{ef}	1.9^{b}	1.2^{c}	1.1^{g}	49.0^{f}	97.8	53.2^{h}
With phytase								
Corn	456	1.1^{h}	1.1^{d}	0.5^{fg}	0.6^{h}	56.1^{ef}	91.2	64.1^{efg}
Hominy feed	494	3.8^{a}	1.5^{c}	1.6^{b}	2.2^{a}	57.6^{de}	98.8	60.1^{fgh}
Bakery meal	472	2.6^{cd}	1.5^{c}	0.8^{e}	1.8^{bcd}	67.5^{c}	94.4	71.2^{de}
DDGS	471	2.2^{f}	0.7^{ef}	0.5^{fg}	1.7^{cde}	78.5^{ab}	94.3	82.8^{abc}
Corn gluten meal	482	1.0^{h}	1.4^{c}	0.2^{h}	0.8^{h}	77.6^{ab}	96.5	87.4^{a}
Corn gluten feed	469	2.4^{def}	0.7^{f}	0.4^{g}	2.0^{ab}	83.1^{a}	93.7	87.1^{a}
Corn germ meal	509	2.6^{c}	1.4^{c}	0.9^{e}	1.7^{cdef}	64.4^{cd}	101.9	68.3^{def}
SEM	17.0	0.1	0.1	0.1	0.1	3.1	3.4	3.3
P-value								

Ingrdient	0.57	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.57	< 0.01
Phytase	0.71	0.79	< 0.01	< 0.01	< 0.01	< 0.01	0.71	< 0.01
Ingredient × phytase	0.75	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.75	0.01

[1]Optiphos 2000 (2,000 FTU/g, Enzyvia, Sheridan, IN.) FTU = phytase units.

[2]Data are means of 6 observations per treatment.

[3]EPL = basal endogenous P loss. This value was measured in pigs fed the P-free diet and determined to be 200 mg/kg DMI (Stein, 2011). The daily basal EPL was calculated by multiplying daily DMI by 200 mg/kg DMI.

[4]Values for STTD were calculated by correcting values for ATTD for basal EPL.

[a-i]Values within a column lacking a common superscript letter are different ($P < 0.05$).

Table 5. Concentration of digestible and metabolizable energy, and apparent total tract digestibility (ATTD) of energy containing corn, hominy feed, bakery meal, dried distillers grains with solubles (DDGS), corn gluten meal, corn gluten feed, and corn germ meal, as-fed basis, Exp. 2[1]

	Diet								
Item	Corn	Hominy feed	Bakery meal	DDGS	Corn gluten meal	Corn gluten feed	Corn germ meal	SEM	*P*-value
Diet									
GE intake, kcal	4,089[b]	4,417[a]	4,068[b]	4,309[a]	4,114[b]	4,140[b]	4,077[b]	107.4	< 0.01
GE in feces, kcal	430.8[d]	940.9[a]	482.0[d]	839.6[b]	411.8[d]	833.3[bc]	751.0[c]	35.6	< 0.01
GE in urine, kcal	129.7[d]	131.6[d]	270.5[a]	180.1[bcd]	212.6[b]	192.6[bc]	153.9[cd]	21.7	< 0.01
ATTD of GE, %	89.4[a]	78.7[c]	88.2[a]	80.6[b]	90.0[a]	79.9[bc]	81.6[b]	0.68	< 0.01
DE, kcal/kg	3,410[b]	3,328[c]	3,414[b]	3,407[b]	3,629[a]	3,164[d]	3,172[d]	27.8	< 0.01
ME, kcal/kg	3,291[b]	3,202[c]	3,159[c]	3,228[bc]	3,421[a]	2,981[d]	3,025[d]	28.1	< 0.01

Ingredients									
ATTD of GE, %	89.4[ab]	78.7[c]	88.2[b]	72.9[d]	92.5[a]	70.6[d]	73.9[d]	1.4	< 0.01
DE, kcal/kg	3,498[bc]	3,399[c]	3,495[bc]	3,556[b]	4,896[a]	3,051[d]	3,073[d]	54.5	< 0.01
DE, kcal/kg of DM	4,032[b]	3,819[c]	3,951[bc]	4,062[b]	5,379[a]	3,553[d]	3,437[d]	61.1	< 0.01
ME, kcal/kg	3,375[b]	3,271[b]	3,233[b]	3,235[b]	4,006[a]	2,721[c]	2,817[c]	63.8	< 0.01
ME, kcal/kg of DM	3,891[b]	3,675[c]	3,655[c]	3,694[bc]	4,400[a]	3,169[d]	3,150[d]	71.5	< 0.01

[a-d]Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1]Data are means of 8 observations per treatment.