Energy and nutrient digestibility of high protein distillers dried grains and corn germ by growing pigs and effects on pig performance, carcass quality, and pork palatability

By

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Energy and nutrient digestibility of high protein distillers dried grains and corn germ by growing pigs and effects on pig performance, carcass quality, and pork palatability

This thesis is approved as a creditable and independent investigation by a candidate for the Master of Animal Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ABSTRACT

Energy and nutrient digestibility of high protein distillers dried grains and corn germ by growing pigs and effects on pig performance, carcass quality, and pork palatability

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A series of experiments were conducted with 2 new co-products from the ethanol industry, i.e., high-protein distillers dried grains (HP DDG) and corn germ. These products are produced by de-hulling and de-germing corn before it enters the fermentation process. Experiment 1 was an energy balance study to measure DE and ME in HP DDG, corn germ, and corn. The DE and ME did not differ between corn and corn germ, but HP DDG contained more ($P < 0.05$) energy than corn and corn germ. Experiment 2 was conducted to measure apparent (ATTD) and true (TTTD) total tract digestibility of P in HP DDG and corn germ. The ATTD and retention of P was lower ($P < 0.05$) in corn germ than in HP DDG. The TTTD of P for HP DDG and corn germ was calculated at 69.3% and 33.7%, respectively. In Exp. 3, apparent (AID) and standardized (SID) ileal digestibility values of CP and AA in HP DDG and corn germ were measured. The AID for CP and all AA except Arg, and the SID for CP and all AA except Arg, Lys, Gly, and Pro were greater ($P < 0.05$) in HP DDG than in corn germ. Pig performance,

carcass composition, and palatability of pork from pigs fed distillers dried grains with solubles (DDGS), HP DDG, and corn germ was investigated in Exp. 4. Pig performance was not affected by the inclusion of DDGS or HP DDG in the diet. However, final BW increased (linear, $P < 0.05$) as corn germ was included in the diet. Belly firmness decreased (linear, $P < 0.05$) as dietary DDGS concentration increased to 20%. Including HP DDG or corn germ in the diets did not affect fat quality except that iodine value increased (linear, $P < 0.05$) in pigs fed HP DDG diets and decreased (linear, $P < 0.05$) in pigs fed corn germ diets. Overall, the palatability of bacon and pork chops was not affected by dietary treatment. In conclusion, feeding 20% DDGS or replacing all the soybean meal with HP DDG in corn-based diets fed to growing-finishing pigs did not negatively affect overall pig performance, carcass composition, muscle quality, or loin and bacon palatability, but may decrease fat quality. Corn germ may have a lower digestibility of energy, P, and most AA than HP DDG; however, feeding 10% corn germ did not negatively affect pig performance, carcass composition, carcass quality or palatability, but increased final BW of pigs and reduced iodine value of belly fat.

Key words: Corn germ, digestibility, distillers dried grains with solubles, high-protein distillers dried grains, performance, pigs

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LIST OF ABBREVIATIONS

AA	Amino acid
AAd	Amino acid content of ileal digesta dry matter
AAf	Amino acid content of the feed dry matter
ADF	Acid detergent fiber
ADFI	Average daily feed intake
ADG	Average daily gain
AID	Apparent ileal digestibility
Ala	Alanine
ANOVA	Analysis of variance
AOAC	Association of Analytical Chemists
Arg	Arginine
Asp	Aspartic acid
ATTD	Apparent total tract digestibility
BW	Body weight
°C	Degrees Celsius
Ca	Calcium
cm	Centimeter
CP	Crude protein
Cr	Chromium
Crd	Chromium content in ileal digesta dry matter

Crf	Chromium content of the feed dry matter
Cu	Copper
Cys	Cysteine
d	Day
DCP	Dicalcium phosphate
DDG	Distillers dried grains
DDGS	Distillers dried grains with solubles
DE	Digestible energy
DM	Dry matter
DMI	Dry matter intake
EAL	Endogenous amino acid losses
Eq.	Equation(s)
Exp.	Experiment
Fe	Iron
g	Grams
GE	Gross energy
G:F	Gain to feed ratio
Glu	Glutamine
Gly	Glycine
h	Hour
H	Hydrogen
HCl	Hydrochloric acid

His	Histidine
HP DDG	High-protein distillers dried grains
Ile	Isoleucine
IU	International units
K	Potassium
Kcal	Kilocalories
kg	Kilograms
Km	Kilometers
L	Liter
Leu	Leucine
LM	Longissimus muscle
LSMEANS	Least square means
Lys	Lysine
m	meter
Mcal	Megacalories
MCP	Monocalcium phosphate
ME	Metabolizable energy
Met	Methionine
Mg	Magnesium
mg	Milligrams
min	Minute
mL	Milliliter

Mn	Manganese
N	Nitrogen
Na	Sodium
NDF	Neutral detergent fiber
NRC	National Research Council
O	Oxygen
P	Phosphorus
Pf	Fecal output of phosphorus dry matter
Phe	Phenylalanine
Pi	Phosphorus intake
Pr	Phosphorus retention
Pro	Proline
Pu	Phosphorus content in the urine
RFS	Renewable fuels standard
SAS	Statistical Analysis System
SBM	Soybean meal
Se	Selenium
SEM	Standard error of the mean
Ser	Serine
SID	Standardized ileal digestibility
Thr	Threonine
Trp	Tryptophan

TTP_{end}	Basal endogenous loss of P
TTTD	True total tract digestibility
Tyr	Tyrosine
US	United States of America
Val	Valine
wk	Week
Zn	Zinc

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CHAPTER 1

Introduction

In 2005, the Energy Policy Act of 2005 was signed into law, which created a national Renewable Fuels Standard (**RFS**). The RFS established that by the year 2012 the US should produce 7.5 billion gallons of ethanol (Renewable Fuels Association, 2006). As the production of ethanol increases, the availability of the co-product distillers dried grains with solubles (**DDGS**) will also increase. It is estimated that in 2012 when RFS is fully implemented there will be 20 million metric tons of DDGS available for livestock producers (Renewable Fuels Association, 2007). Therefore, livestock producers need to know the nutrient composition and digestibility of these co-products so they can be successfully used as a feed source. The nutrient composition and digestibility of DDGS has been previously reported. However, new ethanol production technologies are being introduced that produce new co-products that have not been analyzed for nutrient composition or digestibility. Dakota Gold Marketing (Sioux Falls, SD) has introduced a new bio-refining ethanol technology called BFrac™. This new process de-hulls and de-germs the corn prior to fermentation and increases the ethanol yield from the starch fraction of the corn. The 2 new co-products that could potentially be fed to swine are corn germ, originating from de-germing of the corn, and high-protein distillers dried grains (HP DDG), which is the distillers dried grains (DDG) produced after the de-hulled and de-germed corn has been fermented. However, at this point, no data are available on the digestibility of energy and nutrients in these products and there is no information on the feeding value of these products.

One of the concerns of the swine industry is the pork quality and palatability that results from feeding co-products to pigs. Whitney et al. (2006) reported carcass composition and carcass quality in pigs fed DDGS; however palatability of pigs fed DDGS has not been reported. In addition, pig performance, carcass composition, pork quality, and pork palatability of pigs fed HP DDG and corn germ has not been reported.

Therefore, the objective of this thesis was to evaluate the nutritional value of HP DDG and corn germ by measuring digestibility values for energy, P, and AA. With values obtained from these studies, diets that are balanced on digestible P and AA will be formulated using DDGS, HP DDG, and corn germ. These diets will be fed to growing-finishing pigs to evaluate pig performance, carcass composition, pork quality, and pork palatability.

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CHAPTER 2

Co-products from the fuel ethanol industry and their feeding value for pigs: Literature review

INTRODUCTION

The production of alcohol for fuel, beverage, or industrial use from corn or other cereal grain is a major industry in the US. The production of alcohol for beverage consumption is an ancient technique that dates back 9,000 years to China (E85, 2007) and is still being used today for human consumption. Alcohol has been used for fuel in the US since at least 1908 with the Ford Model T that could be run on either gasoline or pure alcohol (E85, 2007; Renewable Fuels Association, 2007). This technique of using alcohol for fuel has had explosive growth in recent years as shown by an increase of 300% in ethanol production since the year 2000 (Renewable Fuels Association, 2007). This rapid growth results in an increase of co-products that are available for livestock producers. The major co-product produced during ethanol production is distillers dried grains with solubles (**DDGS**). In 2006, 12 million metric tons of DDGS was produced and it is expected to increase to 20 million metric tons by 2012 (Renewable Fuels Association, 2007).

Distillers dried grains with solubles is characterized by the source of grain that is being used during the fermentation process to make ethanol. Ethanol is produced when sugars are fermented, therefore, any feedstuff that is high in sugar or starch can be used to

make ethanol (Renewable Fuels Association, 2007). Currently in the US, corn, barley, cheese whey, waste beverage, sugar, and sorghum are the feedstuffs used in ethanol production (Renewable Fuels Association, 2007). The majority of ethanol in the US utilizes corn to produce ethanol; therefore, the focus of this review will be on DDGS produced from corn.

The age of the plant also characterizes the DDGS that is produced. Ethanol plants that have been built after 1990 are referred to as "new generation" plants, the DDGS that is produced is generally a higher quality product and is more digestible than DDGS produced from older ethanol plants (Spiehs et al, 2002; Shurson et al., 2004).

DISTILLATION PROCESS

The 2 main production processes to produce ethanol are wet milling (Figure 2.1) and dry milling (Figure 2.2). The main difference between the 2 methods is the initial treatment of the grain (Renewable Fuels Association, 2006). In wet milling, the grain is separated into many different components by soaking or "steeping" in water and dilute sulfurous acid for 24 to 48 hours at 55°C (Renewable Fuels Association, 2006). After steeping, the germ is removed and processed to recover the oil (Davis, 2001). The remaining portion of the germ, corn germ meal, is used for animal feed. After the germ has been removed, the remaining corn kernel is screened to remove the bran, which is combined with other co-product streams to produce corn gluten feed (Davis, 2001). The starch slurry that remains goes through centrifugal separators, which causes lighter gluten protein to float to the top. This material is then dried and sold as corn gluten meal

(Davis, 2001). The remaining starch is washed and dried and sold for industrial purposes including ethanol production. After ethanol is produced, the grain that remains is either sold wet or dried to make dried distillers grains (**DDG**). Eighteen-percent of the ethanol produced in the US comes from wet mills (Renewable Fuels Association, 2007).

In dry grinding, the entire corn kernel is ground into a fine meal and processed without separating different components of the grain as in wet milling (Renewable Fuels Association, 2006). Water is added to the meal to form a "mash" and enzymes that convert starch to dextrose are added (Renewable Fuels Association, 2006) because yeast cannot act upon starch but only on sugars. This process is called liquefaction (Davis, 2001). After complete liquefaction of the starch, the mash is "cooked" to kill unwanted lactic acid producing bacteria (Davis, 2001). The mash is then cooled and transferred to fermenters where yeast is added and the conversion of sugar to ethanol and carbon dioxide begins (Renewable Fuels Association, 2006). After fermentation, the mash is referred to as "beer" which is transferred to distillation columns and the ethanol is separated from the remaining "stillage" (Renewable Fuels Association, 2006). The stillage is sent through a centrifuge which separates the solids from the liquids or "solubles". The solubles are either recycled or concentrated in an evaporator to become corn condensed distillers solubles or "syrup" (Davis, 2001). The solids are called wetcake and can either be sold wet, dried to get DDG, or combined with solubles and dried to get DDGS. Eighty-two percent of ethanol plants in the US use dry mill production because of lower initial costs (Renewable Fuels Association, 2007).

DISTILLER'S CO-PRODUCTS

The dry milling process results in 3 co-products as already described; e.g. distillers solubles, DDG, and DDGS. These products have different nutritional properties (Table 2.1). The nutrient concentration in DDGS is approximately 3 times greater than in corn because corn contains approximately 66% starch.

One of the biggest challenges in using DDGS for monogastric animals is knowing the nutrient content and AA digestibility. The digestibility of AA and energy in DDGS has been shown to vary among sources. Thirty-six samples of DDGS originating from 35 different ethanol plants were analyzed (Stein et al., 2005; Pahm et al., 2006a,b; Stein et al., 2006; Urriola et al., 2007) for AA concentration and standardized ileal digestibility (**SID**) of AA was measured in these samples (Table 2.2). Data show that AA concentration and digestibility varies among sources, which is important to realize when formulating diets. Lysine, the 1st limiting AA in swine diets, had a standard deviation of 7.61 for digestibility in the 36 samples of DDGS, which is the largest variation among the indispensable AA. It is believed that Lys may be heat damaged in some samples of DDGS, which results in a lower digestibility of Lys (Cromwell et al., 1993). The drying temperature of DDGS can vary from 126 to 620°C among plants (Shurson et al., 2005), which can cause variations in the amount of heat damage in DDGS. Therefore, it is not surprising that Lys digestibility varies among sources of DDGS.

Spiehs et al. (2002) reported a variation in nutrient content in DDGS within plants. Some of this variation can be explained by the difference in nutrient content of the corn used in the fermentation process. Cromwell et al. (1999) reported that corn

produced in 15 Midwest states ranged from 7.31 to 9.06% crude protein, 0.25 to 0.30% Lys, and 0.22 to 0.29% P. A small difference in the nutrient content of corn will lead to a larger difference in nutrient content of DDGS because nutrients in DDGS are increased approximately 3 fold.

The ratio of solubles to distillers grain that is mixed to produce DDGS also varies among plants (Shurson et al., 2005). There is a variation in nutrient composition between the solubles and distillers grains (Table 2.1). As a consequence, when different proportions of solubles and distillers grains are mixed, a different nutrient composition of DDGS will be the result. The official definition of DDGS states that at least ¾ of the solids of the resultant whole stillage must be combined to name the product DDGS (AAFCO, 2007). However, many ethanol plants add all the solubles to the DDG and others add less than 75%, which increases variability of nutrient composition of DDGS among plants (Shurson et al., 2005).

NUTRIENT AND ENERGY DIGESTIBILITY

Pedersen et al. (2007) reported energy concentrations and digestibility in 10 samples of DDGS (Table 2.3). Dried distillers grains with solubles has a greater GE (5,434 kcal/kg DM) than corn (4,496 kcal/kg DM); however, because DDGS has a lower energy digestibility (76.8%) than corn (90.4%), there is no difference in DE and ME between corn and DDGS. Fastinger and Mahan (2006) and Stein et al. (2006) reported a lower GE and apparent total tract digestibility (**ATTD**) of energy in DDGS than Pedersen et al. (2007). This could be due to differences in the quality of DDGS among these

experiments. In addition, different methodologies were used to measure ATTD in DDGS.

Pedersen et al. (2007) reported values between 50.1 and 68.3% with an average of 59.1% for the ATTD of P in 10 samples of DDGS which is greater then the 19% ATTD of P in corn (Table 2.3). The reason for the greater ATTD of P in DDGS compared with corn may be that some of the bonds that bind P to the phytate complex in corn have been hydrolyzed during the fermentation process (Pedersen et al., 2007). Therefore, more P can be absorbed from DDGS, which results in a greater ATTD of P in DDGS compared with corn. The 59.1% for ATTD of P that Pedersen et al. (2007) reported is in agreement with Stein et al. (2005) who reported an average of 55% for ATTD of P in 4 sources of DDGS.

Amino acid digestibility in DDGS has been reported by Stein et al., 2005; Pahm et al., 2006a,b; Stein et al., 2006; and Urriola et al., 2007 and the results are summarized in Table 2.2. The indispensable AA with the most variation is Lys; all other AA have a medium digestibility and are within the normal range for variation found in other feed ingredients (Stein, 2007).

PERFORMANCE STUDIES

Nursery Experiments

Whitney and Shurson (2004) conducted 2 trials to evaluate the effects of feeding nursery pigs 0, 5, 10, 15, 20, or 25% DDGS. In Exp. 1, pigs were weaned at 19 d and weighed 7 kg and they were fed a 3 phase nursery diet. The first phase was a commercial

pellet diet that was fed for 4 d and pigs were then switched to their respective experimental diets. Phase 2 diets were fed for 14 d and phase 3 diets were fed for 21 d. Experiment 2 pigs were weaned at 16.7 d of age and weighed 5.3 kg. All procedures in this experiment were the same as in Exp. 1. There were no differences for ADG, ADFI, and BW among dietary treatments in Exp. 1. However, in Exp. 2, ADFI decreased linearly in phase 2 as the concentration of DDGS increased in the diet. Therefore, it was concluded that DDGS can be included in nursery diets up to at least 25% if pigs weigh more than 7 kg at weaning without affecting pig performance.

Whitney et al. (2006a) conducted a study to determine if feeding 10% DDGS to *Lawsonia intracellularis* challenged nursery pigs reduced the incidence of intestinal lesions. Feeding 10% DDGS reduced ileum and colon lesion length and prevalence and reduced the severity of lesions in the ileum and colon in challenged pigs. Therefore, it was concluded that including 10% DDGS in nursery diets provided some benefits to pigs subjected to a *Lawsonia intracellularis* challenge.

Grow-Finish Experiments

DeDecker et al. (2005) and Cook et al. (2005) both reported no detrimental effects on pig performance when 0, 10, 20, or 30% DDGS was added to grow-finish diets. DeDecker et al. (2005) also reported an improvement in G:F when pigs were fed 20 or 30% DDGS compared to the 0% treatment. Cook et al. (2005) reported a linear decrease in pig mortality as DDGS inclusion increased. However, Fu et al. (2004), Linneen et al. (2006), and Whitney et al. (2006b) reported a decrease in pig performance as DDGS concentration increased in the diet. Fu et al. (2004) reported a linear decrease in ADFI,

ADG, and BW, but no difference in G:F as DDGS concentrations increased up to 30%. Whitney et al. (2006b) reported that pigs fed 20 or 30% DDGS had reduced ADG compared with pigs fed 0 or 10% DDGS, but G:F was decreased only when pigs were fed 30% DDGS. However, the reduction in ADG was likely a result of inadequate Thr in the diets, which can be solved by formulating diets based on concentrations of digestible AA (Shurson et al., 2005). Whitney et al. (2006b) also reported that ADFI was not affected by the inclusion of up to 30% DDGS to the diet, which is in contrast to Hastad et al. (2004 and 2005). Decreased palatability amplifies with greater concentrations of DDGS in the diet (Hastad et al., 2005). If the source of DDGS with a low palatability is used, it would, therefore, be expected that ADFI would be reduced.

Gestation and Lactation Experiments

Three studies have been conducted to evaluate feeding DDGS to sows. Hill et al. (2005) fed lactating sows 15% DDGS with no negative effects on performance of the sow or piglets. Monegue and Cromwell (1995) fed 40 and 80% DDGS to gestating sows. Gestating sows utilized the 40% and 80% DDGS without impairing reproductive or lactation performance (Monegue and Cromwell, 1995). However, Wilson et al. (2003) reported a decrease in ADFI in lactation if 1st parity sows were fed no DDGS in gestation and then 20% DDGS in lactation. No difference in sow gestation weight gain, pigs born alive per litter, and litter birth weight were observed between sows fed the 0 or 50% DDGS diets during gestation. Therefore, it is concluded that feeding sows 50% DDGS during gestation will support satisfactory reproductive performance, but feeding 0% DDGS in gestation and then 20% DDGS in lactation may reduce feed intake.

Carcass Characteristics

Fu et al. (2004) reported no difference in carcass backfat, loin depth, percent lean, or dressing percent among pigs fed 0, 10, 20, or 30% DDGS. However, Cook et al. (2005) reported a linear decrease in dressing percent when pigs were fed 0, 10, 20, or 30% DDGS, but carcass backfat and lean percent were not different. Whitney et al. (2006b) also reported a linear decrease in dressing percent as DDGS concentration was increased. Previous studies have shown that increasing the fiber content in diets results in a larger cecum and large intestine, which results in a lower dressing percent (Kennelly and Aherne, 1980; Stein et al., 1996; Whittemore et al., 2003). Carcass backfat and percent lean were also not influenced by increasing DDGS concentration in diets fed to grow-finish pigs, however, loin depth was decreased as the DDGS concentration increased (Whitney et al., 2006b). Pigs fed the greater DDGS concentration had a lower slaughter weight, which contributed to the smaller loin depth (Whitney et al., 2006b).

The iodine value of carcass fat is a crude method to determine the saturation level of fat. Iodine can bind to the double bonds in unsaturated fatty acids and the iodine value is defined as the grams of iodine bound per 100g of fat. Therefore, a fat with a low iodine value is more saturated and firmer than a fat with a high iodine value (Averette Gatlin et al., 2005). Iodine value increased linear as concentration of DDGS increased in the diet (Whitney et al., 2006b). The high iodine value correlates with a decrease in belly firmness as DDGS concentration in the diet increases. This decrease in belly firmness indicates a softer belly, which is most likely a consequence of greater concentrations of dietary unsaturated lipids in DDGS (Whitney et al., 2006b) because fatty acid

composition of pork is influenced by the composition of dietary fat (Seerly et al., 1978; Miller et al., 1990; Madsen et al., 1992). A soft, thin belly is a problem in the meat industry because it produces more miscuts and a higher percentage yield of lower-quality product (Morgan et al., 1994).

ENHANCED DDGS AND THE FUTURE OF ETHANOL PRODUCTION

Dakota Gold Marketing (Sioux Falls, SD) has introduced a new bio-refining ethanol technology called BFrac™ (Figure 2.3). This new process de-hulls and de-germs the corn through dry milling prior to fermentation and increases the ethanol yield from the starch fraction of the corn (Dakota Gold Marketing, 2007a). Three new co-products are produced from this process. These 3 co-products are corn germ, high-protein distillers dried grains **(HP DDG**), and bran cake. Corn germ originates from de-germing the corn prior to fermentation. High-protein distillers dried grains is the DDG produced after the de-hulled and de-germed corn has been fermented. Bran cake is condensed distillers solubles added to the fiber (bran) fraction of the kernel, this product can either be dried or remain wet.

The nutrient content of HP DDG and corn germ is reported in Table 2.1. High-protein distillers dried grains contains more CP, and less fat, ADF, NDF, and P than conventional DDG. The fiber is removed from the HP DDG when it is de-hulled and the fat and P are removed during the de-germing process. Corn germ has a greater concentration of CP, crude fat, NDF, ADF, and P than corn and is potentially a good feed ingredient for swine diets. The bran cake is a high fiber, low energy product that is not

expected to be marketed to swine. Parsons et al. (2006) reported P and Lys digestibility in HP DDG and corn germ in chickens. Corn germ had a lower bioavailability of P (25%) than HP DDG (58%); however, corn germ had a greater Lys digestibility (91%) than HP DDG (73%).

Producing ethanol from cellulose is currently being researched. In 2005, the Department of Energy was authorized, under the Energy Policy Act of 2005, to provide hundreds of millions of dollars in grants and loan guarantees to assist ethanol producers in developing and building commercial-scale cellulosic ethanol facilities (Renewable Fuels Association, 2007). Using cellulose to produce ethanol will expand the type and amount of material available for ethanol production and may increase the amount of ethanol that can be potentially produced (Renewable Association, 2007). Cellulosic ethanol facilities will produce different co-products than the products that are produced now. These new products need to be researched to determine if they can be fed to livestock.

CONCLUSION

The rapid growth of the US ethanol industry has increased the supply of DDGS available for livestock. One of the biggest problems with DDGS is that the nutrient composition varies among sources. Nutrient composition should be determined before formulating diets. In addition, digestibility of AA varies among samples so high quality DDGS should be purchased. Research has shown that DDGS can be incorporated into swine diets without detrimental effects. It is recommended to include DDGS up to 20%

in nursery, grow-finish, and lactation diets; however it is not recommended to use DDGS in diets fed to nursery pigs during the initial 2 weeks post weaning. Furthermore, it is recommended that 40% DDGS can be fed to gestating sows.

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Table 2.1. Nutrient composition in corn and corn co-products (DM basis)

Item	Corn[4]	Distillers solubles[4]	DDG[1, 4]	DDGS[2, 5]	HP DDG[3, 6]	Corn germ[6]
CP, %	9.33	29.02	26.38	30.60	40.00	17.50
Crude fat, %	4.38	9.89	8.40	10.70	4.80	20.20
NDF, %	10.79	26.96	42.98	43.60	15.80	21.70
ADF, %	3.15	8.15	18.62	11.80	9.70	6.50
Ca, %	0.03	0.32	0.11	0.06	0.04	0.02
P, %	0.31	1.12	0.43	0.89	0.48	1.66
Indispensable AA, %						
Arginine	0.42	0.98	0.96	1.29	1.30	1.25
Histidine	0.26	0.72	0.67	0.77	1.40	0.49
Isoleucine	0.31	1.32	1.01	1.12	1.64	0.51
Leucine	1.11	2.45	2.80	3.55	5.52	1.06
Lysine	0.29	0.89	0.79	0.83	1.06	0.84
Methionine	0.19	0.55	0.46	0.55	0.77	0.31
Phenylalanine	0.44	1.50	1.05	1.47	2.22	0.47
Threonine	0.33	1.12	0.66	1.13	1.20	0.60
Tryptophan	0.07	0.25	0.21	0.24	0.24	0.24
Valine	0.44	1.63	1.32	1.50	2.31	0.80
ME (swine), kcal/kg	3,843	3,201	2,888	3,827	3,740	4,532

[1]DDG = distillers dried grains.

[2]DDGS = distillers dried grains with solubles.

[3]HP DDG = high-protein distillers dried grains.

[4]Data from NRC (1998).

[5]Data from Spiehs et al. (2002).

[6]Data from Dakota Gold Marketing (2007b).

Table 2.2. Concentration and SID[1] of CP and AA in 36 samples of DDGS[2] fed to growing pigs[3]

Item	Concentration in DDGS[2], %				SID[1] of DDGS[2], %			
	Average	Low	High	SD	Average	Low	High	SD
Crude protein	27.5	24.1	30.9	1.8	72.8	63.5	84.3	5.33
Indispensable AA								
Arginine	1.16	0.95	1.41	0.10	81.1	74.1	92.0	5.18
Histidine	0.72	0.56	0.84	0.07	77.4	70.0	85.0	4.58
Isoleucine	1.01	0.87	1.31	0.09	75.2	66.5	82.6	4.77
Leucine	3.17	2.76	4.02	0.32	83.4	75.1	90.5	3.85
Lysine	0.78	0.54	0.99	0.09	62.3	43.9	77.9	7.61
Methionine	0.55	0.46	0.71	0.08	81.9	73.7	89.2	4.12
Phenylalanine	1.34	1.19	1.62	0.11	80.9	73.5	87.5	3.94
Threonine	1.06	0.89	1.71	0.20	70.7	61.9	82.5	5.26
Tryptophan	0.21	0.12	0.34	0.04	69.9	54.2	80.1	6.98
Valine	1.35	1.15	1.59	0.11	74.5	65.8	81.9	4.72
Dispensible AA (%)								
Alanine	1.94	1.58	2.79	0.21	77.9	59.7	85.0	4.46
Aspartic Acid	1.83	1.56	2.13	0.14	68.6	59.4	75.9	4.75
Cysteine	0.53	0.37	0.75	0.11	73.6	65.6	80.7	4.64
Glutamic Acid	4.37	3.05	6.08	0.68	80.4	67.4	88.3	5.48

Glycine	1.02	0.88	1.20	0.06	63.5	46.8	87.0	10.97
Proline	2.09	1.74	2.50	0.16	74.4	32.0	125.9	22.12
Serine	1.18	0.94	1.45	0.13	75.6	59.6	82.8	5.14
Tyrosine	1.01	0.83	1.31	0.16	80.9	74.6	88.9	3.79

[1]SID = standardized ileal digestibility.

[2]DDGS = distillers dried grains with solubles.

[3]Data from Stein et al., 2005; Pahm et al., 2006a,b; Stein et al., 2006; and Urriola et al., 2007.

Table 2.3. Concentration and digestibility of energy and P in corn and 10 samples of DDGS[1] fed to growing pigs[2, 3]

Item	Ingredient: Corn	DDGS[1]			
		Average	Low	High	SD
Energy					
GE, kcal/kg DM	4,496	5,434	5,272	5,592	292
Apparent total tract digestibility, GE, %	90.4	76.8	73.9	82.8	2.73
DE, kcal/kg DM	4,088	4,140	3,947	4,593	205
ME, kcal/kg DM	3,989	3,897	3,674	4,336	210
Phosphorus					
Total P, %	0.20	0.61	0.51	0.74	0.90
Total P, % DM	0.23	0.70	0.57	0.85	0.10
Apparent total tract digestibility, P, %	19	59	50	68	5.17
Digestible P, %	0.04	0.36	0.28	0.47	0.06

[1]DDGS = distillers dried grains with solubles.

[2]Data from Pedersen et al., 2007.

[3]All data are based on 11 observations per treatment.

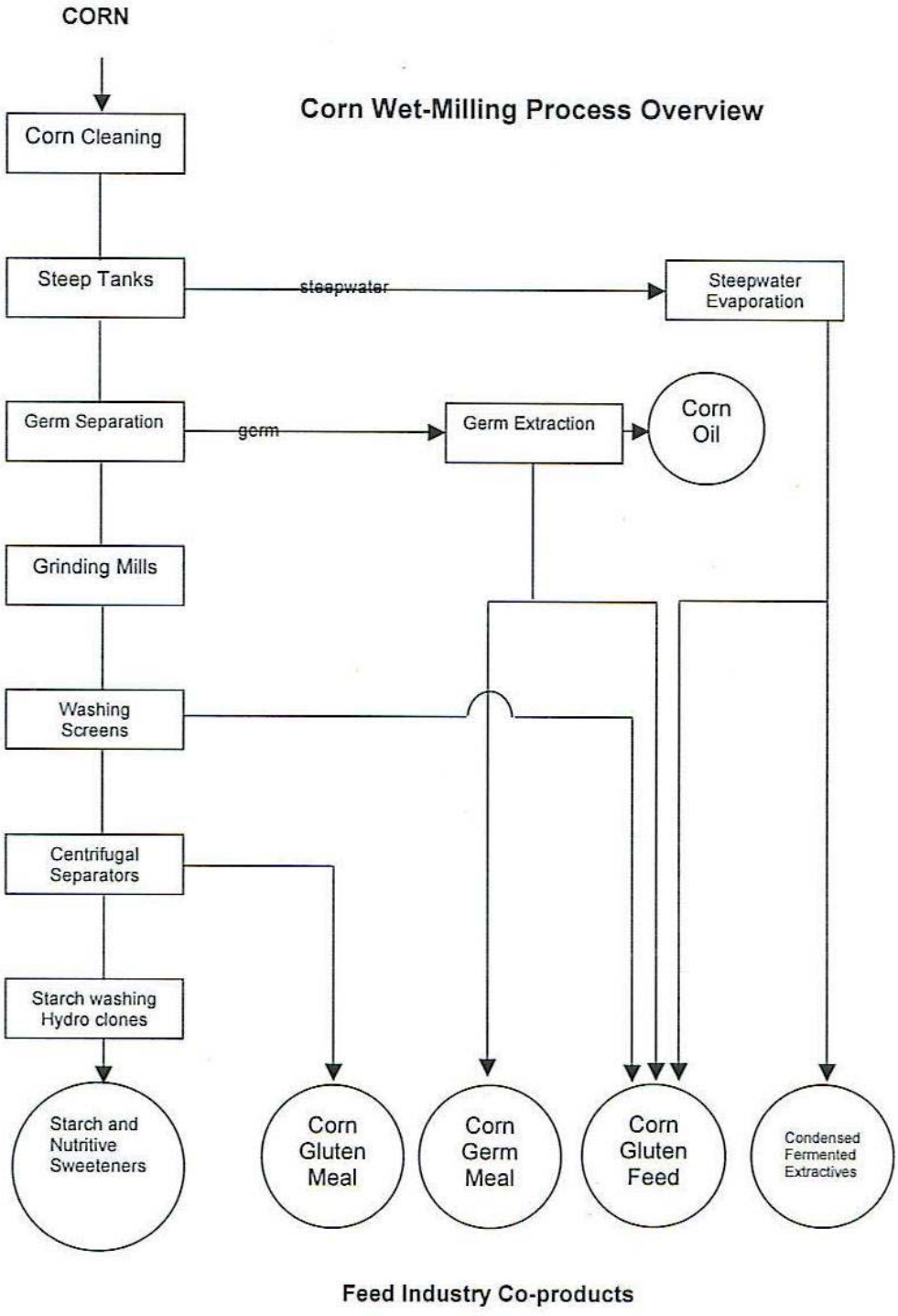

Figure 2.1. Wet milling process steps and co-products (Davis, 2001)

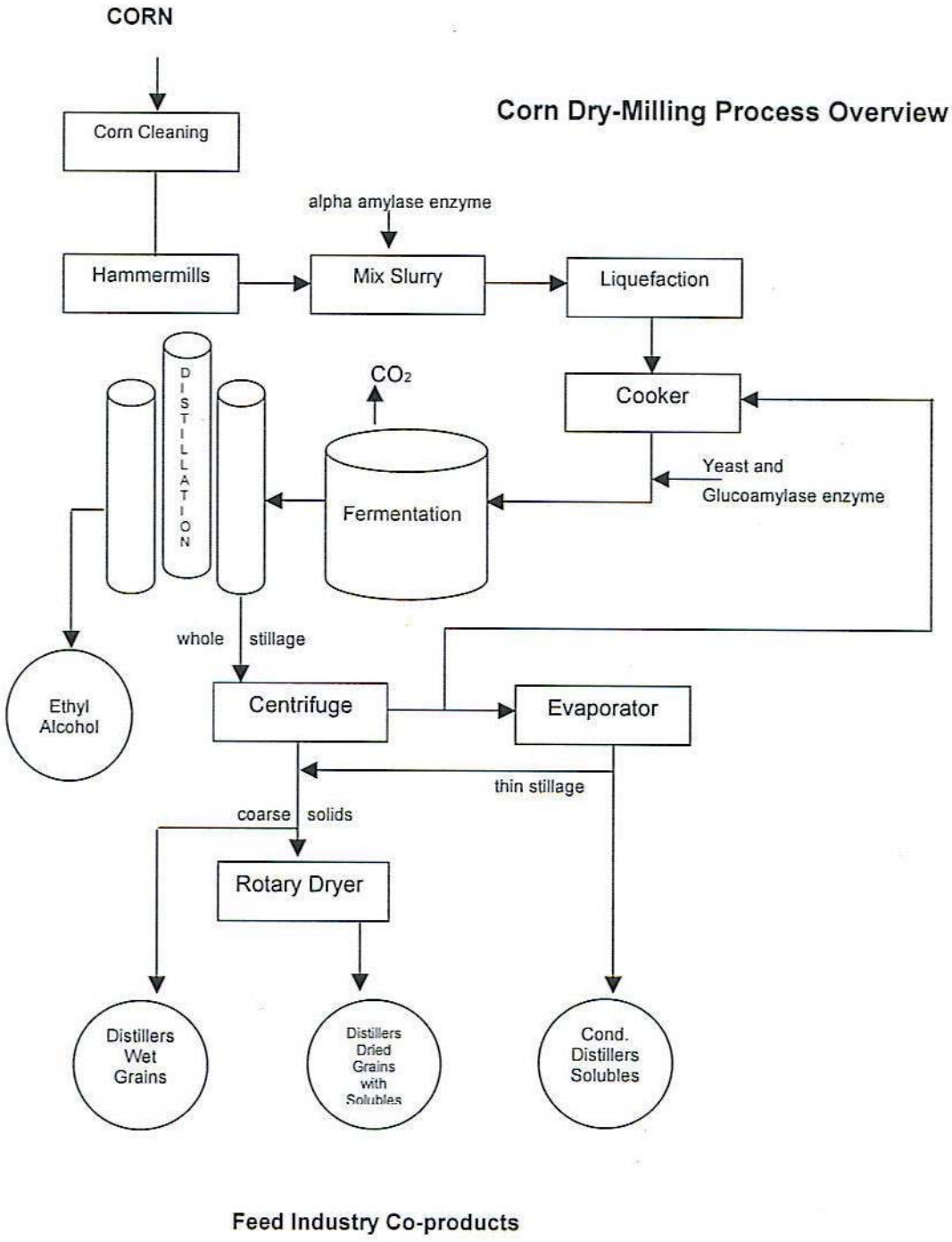

Figure 2.2. Dry milling process steps and co-products (Davis, 2001)

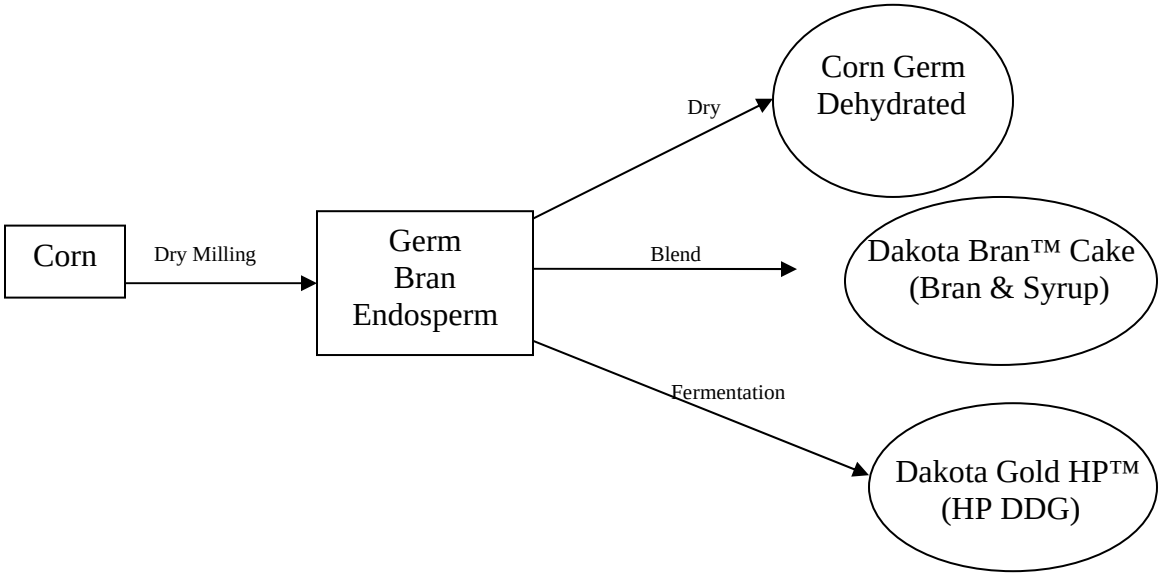

Figure 2.3. BFrac™ process steps and co-products (Dakota Gold Marketing, 2007a)

CHAPTER 3

Energy, amino acid, and phosphorus digestibility of high-protein distillers dried grain and corn germ fed to growing pigs

ABSTRACT: Three experiments were conducted to measure energy, P, and AA digestibility in 2 new co-products from the ethanol industry, i.e., high-protein distillers dried grains (HP DDG) and corn germ. These products are produced by de-hulling and de-germing corn before it enters the fermentation process. Experiment 1 was an energy balance experiment conducted to measure DE and ME in HP DDG, corn germ, and corn. Six growing pigs (initial BW: 48.9 ± 1.99 kg) were placed in metabolism cages and fed diets based on corn, corn and HP DDG, or corn and corn germ. Pigs were allotted to a replicated 3 × 3 Latin square design. The DE and ME did not differ between corn and corn germ (4,056 vs. 3,979 kcal DE/kg DM and 3,972 vs. 3,866 kcal ME/kg DM), but HP DDG contained more ($P < 0.05$) energy (4,763 kcal DE/kg DM and 4,476 kcal ME/kg DM) than corn and corn germ. Experiment 2 was conducted to measure the apparent (ATTD) and true (TTTD) total tract digestibility of P in HP DDG and corn germ. Thirty growing pigs (initial BW: 33.2 ± 7.18 kg) were placed in metabolism cages and fed a diet based on HP DDG or corn germ. A P-free diet was also used. Pigs were assigned to treatments in a randomized complete block design with 10 replications per treatment. The ATTD and the retention of P were calculated for the diets containing HP DDG and corn germ and the endogenous loss of P was estimated from pigs fed the P-free diet. The

ATTD was lower ($P < 0.05$) in corn germ (28.6%) than in the HP DDG (59.6%). The retention of P was also lower ($P < 0.05$) in pigs fed corn germ (26.7%) than in pigs fed HP DDG (58.9%). The endogenous loss of P was estimated at 211 ± 39 mg per kg DMI. The TTTD of P for HP DDG and corn germ was calculated at 69.3% and 33.7%, respectively. In Exp. 3, apparent (AID) and standardized (SID) ileal digestibility values of CP and AA in HP DDG and corn germ were measured using 6 growing pigs (initial BW: 78.2 ± 11.4 kg) allotted to a replicated 3 × 3 Latin square design. The AID for CP and all AA except Arg, and the SID for CP and all AA except Arg, Lys, Gly, and Pro were greater ($P < 0.05$) in HP DDG than in corn germ. It is concluded that HP DDG has a greater digestibility of energy, P, and most AA than corn germ.

Key words: Amino acids, corn germ, digestibility, energy, high-protein distillers dried grains, pigs

INTRODUCTION

Distillers dried grains with solubles (**DDGS**) is a co-product of the fuel ethanol industry. In recent years, there has been a rapid increase in ethanol production. Currently, there are 143 ethanol plants in production or under construction in the US. In 2005, 9 million metric tons of DDGS were produced. (Renewable Fuels Association, 2006) As a result of the increase in DDGS production, the quantity of DDGS used in swine diets has also increased.

Dakota Gold Marketing (Sioux Falls, SD) has introduced a new bio-refining ethanol technology called BFrac™. This new process de-hulls and de-germs the corn before it enters the fermentation process. The process is believed to increase ethanol yield and 2 new co-products, high-protein distillers dried grains (**HP DDG**) and corn germ, are also produced.

The new HP DDG contains more CP, and less fat, ADF, NDF, and P than conventional DDG. The reason for these changes is that much of the fiber is removed during de-hulling and fat and P are removed during de-germing.

The other co-products of the BFrac™ technology are corn germ and bran cake. Corn germ has a greater concentration of CP, fat, ADF, NDF, and P than corn and is a potential feed ingredient for swine. In contrast, bran cake is not expected to be marketed to the swine industry.

The objective of the current experiments were to evaluate the nutritional value of HP DDG and corn germ for growing pigs by measuring digestibility values for energy, P, and AA.

MATERIALS AND METHODS

General Procedure

Three experiments were conducted to determine the energy, P, and AA digestibility of HP DDG and corn germ fed to growing pigs. Pigs used in the experiments were the offspring of SP-1 boars and Line 13 sows (Ausgene Intl. Inc.,

Gridley, IL). The Institutional Animal Care and Use Committee at South Dakota State University reviewed and approved the experiments (# 05-A033).

Experiment 1

Experiment 1 was designed to measure DE and ME in HP DDG and corn germ by growing pigs. Six growing barrows (initial BW: 48.9 ± 1.99 kg) were placed in metabolism cages and allotted to a replicated 3 × 3 Latin square design with 3 periods and 3 pigs per square. A feeder and a nipple drinker were installed in each cage.

Three diets were prepared (Table 3.2). The first diet was a corn based diet that contained 97.6% (as-fed basis) corn. The second diet was a HP DDG based diet with 47.7% HP DDG and 50% corn. The third diet was a corn germ based diet that contained 47.8% corn germ and 50% corn. Vitamins and minerals were included in all diets to meet or exceed estimated nutrient requirements for growing pigs (NRC, 1998).

Feed was supplied to the pigs at a daily level of 2.5 times the estimated maintenance requirement for energy (i.e., 106 kcal ME/$kg^{0.75}$; NRC, 1998). The ME was calculated at 3,338, 3,494, and 3,710 kcal ME per kg (as-fed basis) in the corn diet, HP DDG diet, and the corn germ diet, respectively. The daily allotment of feed was divided into 2 equal meals and fed at 0800 and 1700. Each pig was fed each of the 3 diets during 1 experimental period. Water was available at all times.

Pigs were weighed at the beginning of each period and the amount of feed supplied each d was recorded. Each period lasted 12 d. The pigs were allowed a 5 d adaptation period to their assigned diet. Chromic oxide (0.5%) and ferric oxide (0.5%), were added to the diet in the morning meals on d 6 and 11, respectively. Fecal

collections commenced when chromic oxide first appeared in the feces after d 6 and collection ceased when ferric oxide appeared in the feces after d 11 as previously described (Adeola, 2001). Fecal matters were collected twice daily and stored at -20°C until the end of the period. Urine collection was initiated on d 6 at 1700 and ceased on d 11 at 1700. Urine buckets were placed under the metabolism cages that allowed for total collection. The buckets were emptied in the morning and afternoon and a preservative of 50 mL of 6 *N* sulfuric acid was added to each bucket each time they were emptied. All collected urine samples were weighed and a 20% sub-sample was collected and stored at -20°C. At the end of the experiment, urine and fecal samples were thawed and mixed within animal and diet, and a sub-sample was taken for chemical analysis. Fecal samples were dried in a forced air oven and ground before the sub-sample was collected.

All samples were analyzed in duplicate. Fecal samples, diets, and feed ingredients were analyzed for DM (procedure 930.15; AOAC, 2005). Feed ingredients were analyzed for ash (procedure 942.05; AOAC, 2005), ether extract (Thiex et al., 2003), ADF and NDF (procedure 973.18; AOAC, 2005), and starch (Knudsen, 1997). Fecal samples, urine, diets, and feed ingredients were analyzed for Kjeldahl N (Thiex et al., 2002) and for GE using bomb calorimetry (Parr Instruments, Moline, IL). Concentrations of DE and ME were then calculated for each diet using the direct approach (Adeola, 2001) by subtracting the amount of energy lost in the feces and in feces and urine, respectively, from the intake of GE of each diet. The DE and ME in the corn diet was then divided by 0.976 to calculate the DE and ME in corn. By subtracting half of the energy concentration in corn from the HP DDG and corn germ diets, the

amount of DE and ME in each of these 2 feed ingredients were then calculated using the difference procedure (Adeola, 2001). By further correcting these values for DM in corn, HP DDG, and corn germ (85.95, 92.43, and 92.24%, respectively), the DE and ME in the ingredient DM were calculated. The N balance for each diet and each feed ingredient was calculated using a similar approach.

Data were analyzed by ANOVA using the PROC MIXED procedure (Littell et al., 1996) in SAS (SAS Stat. Inc., Cary, NC). Homogeneity of the data was verified using the UNIVARIATE procedure of SAS. The residual vs. predicted plot procedure was used to analyze data for outliers; however, no outliers were identified. An analysis of variance was conducted with diet as the main effect and period as random effect. Treatment means were separated using the LSMEANS statement and the PDIFF option of PROC MIXED. The pig was the experimental unit and an alpha level of 0.05 was used to assess significance among means.

Experiment 2

Experiment 2 was designed to measure apparent (**ATTD**) and true **(TTTD)** total tract digestibility values for P in HP DDG and corn germ by growing pigs. Thirty growing barrows (initial BW: 33.2 ± 7.18 kg) were placed in metabolism cages in a randomized complete block design with 3 diets and 10 pigs per diet. The metabolism cages were similar to those used in Exp. 1.

Three diets were prepared (Table 3.3). The first diet contained HP DDG at a concentration of 60% (as-fed basis), whereas the second diet contained corn germ in the amount of 42.5% (as-fed basis). Corn germ and HP DDG were the only P containing

ingredients in these diets. The last diet was a P-free diet used to estimate basal endogenous losses of P (Petersen and Stein, 2006). Vitamins and micro minerals were included in all diets to meet or exceed estimated nutrient requirements for growing pigs (NRC, 1998). Limestone was included at a concentration of 1.2% in the HP DGG diet, 1.55% in the corn germ diet, and 0.8% in the P-free diet. Soybean oil was added to the HP DDG diet (3%) and to the P-free diet (4%), but because of the high fat concentration in corn germ, no oil was added to this diet. Sugar was added at 15% in the HP DDG and corn germ diets and 20% in the P-free diet to increase palatability. A pork gelatin with a bloom of 100 (Gelita Gelatine USA Inc., Sioux City, IA) was added to the corn germ diet and to the P-free diet at 10% and 20%, respectively, to increase the concentration of AA. Crystalline AA were also used in all diets to meet current requirement estimates (NRC, 1998). Solka floc, a synthetic source of fiber, was included in the P-free diet (4%) to increase the concentration of crude fiber. The P-free diet was assumed to contain no K and Mg; therefore, these minerals were supplied in the form of potassium carbonate (0.4%) and magnesium oxide (0.1%), respectively.

Feed was supplied to the pigs at a daily level of 2.5 times the estimated maintenance requirement for energy. The ME was calculated at 3,654, 3,491, and 3,452 kcal ME per kg (as-fed basis) in the HP DDG diet, corn germ diet, and P-free diet, respectively. The daily allotment of feed was divided into 2 equal meals and fed at 0800 and 1700 each day. Water was available at all times through a nipple drinker.

Fecal matter and urine samples were collected, stored, dried, and processed as described for Exp. 1. All samples were analyzed in duplicate. Fecal samples, diets, and

feed ingredients were analyzed for DM (procedure 930.15; AOAC, 2005). Concentrations of Ca were determined in fecal matter, urine, diets, and feed ingredients using an atomic absorption spectrophotometer (procedure 927.02; AOAC, 2005) and P was determined in these samples using a spectrophotometer (procedure 931.01; AOAC, 2005). The ATTD of P was calculated using Eq. [1] (Petersen and Stein, 2006):

$$\text{ATTD (\%)} = ([\text{Pi} - \text{Pf}]/\text{Pi}) \times 100, \quad [1]$$

where ATTD is the apparent total tract digestibility (%) for P; Pi is the total P-intake from d 6 to 11 of each period in grams, and Pf is the total fecal output of P originating from the feed fed from d 6 to 11, in grams. The same equation was used to calculate the ATTD for Ca.

Phosphorus retention for each pig and period was calculated using Eq. [2] (Petersen and Stein, 2006):

$$\text{Pr (\%)} = ([\text{Pi} - \{\text{Pf} + \text{Pu}\}]/\text{Pi}) \times 100, \quad [2]$$

where Pr is the retention (%), and Pu is the urinary output of P from d 6 to 11, in grams.

The P-free diet was used to calculate the basal endogenous losses of P according to Eq. [3] (Petersen and Stein, 2006):

$$\text{TTP}_{\text{end}} = ([\text{Pf}/\text{Fi}] \times 1{,}000 \times 1{,}000), \quad [3]$$

where TTP_{end} is the basal endogenous loss of P (mg/kg DMI) and Fi is the total feed intake, in grams DM.

The TTTD of P was calculated using Eq. [4] (Petersen and Stein, 2006):

$$\text{TTTD (\%)} = ([\text{Pi} - \{\text{Pf} - \text{TTP}_{\text{end}}\}/\text{Pi}]) \times 100, \quad [4]$$

where TTTD is the true total tract digestibility (%) of P.

Data were analyzed by ANOVA using the PROC MIXED procedure (Littell et al., 1996) in SAS (SAS Stat. Inc., Cary, NC). Homogeneity of the data was verified using the UNIVARIATE procedure of SAS. The residual vs. predicted plot procedure was used to analyze data for outliers, 1 outlier was observed (greater than 2 times the standard deviation) and removed. An analysis of variance was conducted with diet as the main effect. In the first model, all means except data for P digestibility, P absorption, and P retention were compared among all 3 diets. In the second model, means for P digestibility, P absorption, and P retention were compared between HP DDG and corn germ. Treatment means were separated using the LSMEANS statement and the PDIFF option of PROC MIXED. The pig was the experimental unit in all analyses and an alpha level of 0.05 was used to assess significance among means.

Experiment 3

Experiment 3 was designed to measure apparent (**AID**) and standardized (**SID**) ileal digestibility values for AA in HP DDG and corn germ by growing pigs. Six growing barrows (initial BW: 78.2 ± 11.4 kg) were equipped with a T-cannula in the distal ileum using procedures adapted from Stein et al. (1998). Pigs were allowed a 2-wk recovery period following the surgery before the experiment was initiated. During that period, a standard corn soybean meal-based grower diet (18% CP) was provided. Pigs were housed individually in 1.2 × 1.8-m pens in an environmentally controlled building (22°C). A feeder and a nipple drinker were installed in each pen.

Three diets were prepared (Tables 3.4 and 3.5). The first diet contained HP DDG at a concentration of 50% (as-fed basis), whereas the second diet contained corn germ in

the amount of 50% (as-fed basis). Corn germ and HP DDG were the only AA containing ingredients in these diets. The last diet was a N-free diet used to estimate basal endogenous losses of CP and AA. Soybean oil was included in all diets at 3%. Sugar was included at 35% in the HP DDG and corn germ diets and 20% in the N-free diet to increase palatability. Chromic oxide (0.4%) was included in all diets as an indigestible marker. Solka floc was included in the N-free diet (3%) to increase the concentration of crude fiber. The feed ingredients that were included in the N-free diet were assumed to contain no K and Mg; therefore, these minerals were supplied in the form of potassium carbonate and magnesium oxide, respectively. Vitamins and micro minerals were included in all diets to meet or exceed estimated nutrient requirements for growing pigs (NRC, 1998).

Feed was supplied to the pigs at a daily level of 3 times the estimated maintenance requirement for energy. The ME was calculated at 3,534, 3,775, and 3,751 kcal ME per kg (as-fed basis) in the HP DDG diet, the corn germ diet, and the N-free diet, respectively. The daily allotment of feed was divided into 2 equal meals and fed at 0800 and 1700 each day. Water was available at all times through a nipple drinker.

Pigs were allotted to a replicated 3 × 3 Latin square design with 3 periods and 3 pigs per square. Pigs were weighed at the beginning of each period and the amount of feed supplied each d was recorded. Each experimental period lasted 7 d. The initial 5 d of each period were used as an adaptation period to the diet, whereas the remaining 2 d were used for digesta collections in 9-h periods as described by Stein et al. (1999). Briefly, a 225-mL plastic bag was attached to the cannula barrel using a cable tie, and

digesta that flowed into the bag were collected. Bags were removed whenever they were filled with digesta, or at least once every 30 min. They were then immediately frozen at -20°C to prevent bacterial degradation of AA in the digesta.

At the conclusion of the experiment, ileal samples were thawed, mixed within animal and diet, and a subsample was taken for chemical analysis. All digesta samples were freeze-dried and finely ground before chemical analysis. All samples were analyzed in duplicate. Dry matter was analyzed in samples of digesta, diets, and feed ingredients (procedure 930.15; AOAC, 2005). Amino acids were analyzed in HP DDG, corn germ, all diets, and ileal samples on a Beckman 6300 Amino Acid Analyzer (Beckman Instruments Corp., Palo Alto, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Before analysis, samples were hydrolyzed with 6 *N* HCL for 24 h at 110°C (procedure 994.12; AOAC, 2005). Methionine and cysteine were determined as methionine sulfone and cysteic acid after cold perfomic acid oxidation before hydrolysis (procedure 994.12, alt. 3; AOAC, 2005). Tryptophan was determined after hydrolysis with NaOH for 22 h at 110°C (procedure 988.15, alt. 1; AOAC, 2005). The Cr concentrations in digesta and diets were determined according to the procedure of Fenton and Fenton (1979).

The AID for AA in the diets containing HP DDG or corn germ were calculated. These values also represent the digestibility for HP DDG and corn germ, respectively. Equation [5] (Stein et al., 2006b) was used for these calculations:

$$AID = 100 - (AAd/AAf) \times (Crf/Crd) \times 100\% \quad [5]$$

where AID is the apparent ileal digestibility of an AA (%), AAd is the AA concentration in the ileal digesta DM, AAf is the AA concentration in the feed DM, Crf is the chromium concentration in the feed DM, and Crd is the chromium concentration in the ileal digesta DM. The AID for CP was calculated using the same equation.

The basal endogenous loss (**EAL**) to the distal ileum of each AA was determined based on the flow obtained after feeding the N-free diet using Eq. [6] (Stein et al., 2006b):

$$EAL = [AAd \times (Crf/Crd)] \quad [6]$$

where EAL is the basal ileal endogenous loss of an AA (g/kg of DMI), AAd is the concentration of that AA in the digesta DM, Crf is the chromium concentration in the feed DM, and Crd is the chromium concentration in the ileal digesta DM. The basal endogenous flow of CP was determined using the same equation.

By correcting the AID for the EAL for each AA, SID values were calculated for each diet using Eq. [7] (Stein et al., 2006b):

$$SID = [AID + (EAL/AAf)] \quad [7]$$

where SID is the standardized ileal digestibility (%) of an AA. The SID for CP was determined using the same equation.

Data were analyzed by ANOVA using the PROC MIXED procedure (Littell et al., 1996) in SAS (SAS Stat. Inc., Cary, NC). Homogeneity of the data was verified using the UNIVARIATE procedure of SAS. The residual vs. predicted plot procedure was used to analyze data for outliers, 1 outlier was observed (greater than 2 times the standard deviation) and removed. An analysis of variance was conducted with diet as the main

effect and pig and period as random effects. Treatment means were separated using the LSMEANS statement and the PDIFF option of PROC MIXED. The pig was the experimental unit and an alpha level of 0.05 was used to assess significance between means.

RESULTS

Energy Digestibility

The digestibility and retention of energy and N in experimental diets are shown in Table 3.6. There was no difference in the GE intake among diets. The fecal excretion of GE did not differ between the corn and the HP DDG diets (533 and 682 kcal, respectively), but the corn germ diet (1,109 kcal) had a greater ($P < 0.01$) fecal excretion of energy. The corn and corn germ diets did not differ in urinary excretion of energy; however, the HP DDG diet had a greater ($P < 0.01$) excretion of GE than the other diets. In addition, DE and ME were greater ($P < 0.01$) in the HP DDG diet compared with the corn or the corn germ diet. The ATTD for GE did not differ in pigs fed the corn and the HP DDG diets (89.6 and 88.4%, respectively); however, the corn germ diet had a lower ($P < 0.01$) ATTD for GE (81.2%) than the other 2 diets.

Nitrogen intake and urinary excretion of N did not differ between the corn (18.7 and 7.6 g, respectively) and the corn germ (23.9 and 8.2 g, respectively) diets, but the HP DDG diet had a greater ($P < 0.001$) N-intake and urinary excretion than the other 2 diets (57.7 and 23.3 g, respectively). The HP DDG and corn germ diets did not differ in fecal excretion of N; however, the corn diet had a lower ($P < 0.05$) fecal excretion of N

compared with the other 2 diets. Nitrogen absorbed, N retained, and ATTD of N did not differ between the corn and the corn germ diets, but these values were greater ($P < 0.001$) for the HP DDG diet than for the other diets. When N-retention was calculated as a percentage of N-intake, the retention of N did not differ among diets (37, 51, and 48% for pigs fed corn, HP DDG, and corn germ diets, respectively).

The digestibility and retention values of energy and N in corn, HP DDG, and corn germ are shown in Table 3.7. Pigs fed corn germ had a greater ($P < 0.01$) fecal excretion of energy (836 kcal) compared with the fecal excretion of energy from pigs fed corn (546 kcal) or HP DDG (409 kcal). Corn and corn germ did not differ in urinary excretion of energy; however, pigs fed HP DDG had a greater ($P < 0.05$) excretion of energy in the urine than pigs fed the other ingredients (92, 73, and 173 kcal, respectively). The DE and ME did not differ between corn and corn germ, but HP DDG had greater ($P < 0.01$) values for DE and ME than the other ingredients (4,056, 3,979, and 4,763 kcal DE/kg DM; 3,972, 3,866, and 4,476 kcal ME/kg DM for corn, corn germ, and HP DDG, respectively). The ATTD for GE was lower ($P < 0.01$) in corn germ (74.6%) than in corn (89.6%) and HP DDG (88.2%).

Nitrogen intake and urinary excretion of N did not differ between pigs fed corn (19.2 and 7.8 g, respectively) and corn germ (14.3 and 4.3 g, respectively), but pigs fed HP DDG (48.1 and 19.5 g, respectively) had greater ($P < 0.01$) urinary N-losses than pigs fed the other ingredients. There was no difference in fecal N excretion among diets (3.1, 4.0, and 2.8 g for pigs fed corn, HP DDG, and corn germ, respectively). Pigs fed HP DDG had greater ($P < 0.01$) values for N absorbed, N retained, and ATTD of N (44.1 g,

24.6 g, and 92.0%, respectively) than pigs fed corn (16.1 g, 8.4 g, and 82.7%, respectively) or corn germ (11.5 g, 7.2 g, and 80.3%, respectively). When N-retention was calculated as a percentage of N-intake, the retention of N did not differ among ingredients (37, 53, and 51% for pigs fed corn, HP DDG, and corn germ, respectively).

Phosphorus Digestibility

The digestibility and retention values for Ca and P are shown in Table 3.8. Feed intake did not differ between the HP DDG (825 g) and the P-free (900 g) diets, but intake of the corn germ diet (671 g) was lower ($P < 0.05$) than for the other diets. The HP DDG and corn germ diets did not differ in Ca intake; however, the P-free diet had a lower ($P < 0.05$) intake of Ca than the other 2 diets (3.38, 3.37, and 2.58 g, respectively). Phosphorus intake was lower ($P < 0.01$) in the HP DDG diet compared with the corn germ diet (2.09 vs. 3.82 g).

Calcium in the feces and P in the urine did not differ between the HP DDG and the P-free diets, but pigs fed the corn germ diet had greater losses ($P < 0.05$) compared with pigs fed the other diets. Fecal excretion of P was lower ($P < 0.01$) from pigs fed the HP DDG diet compared with pigs fed the corn germ diet (0.82 vs. 2.74 g), but pigs fed the P-free diet had the lowest ($P < 0.01$) excretion of P (0.19 g). Pigs on all treatment diets had different ($P < 0.01$) excretions of Ca in the urine (0.77, 0.21, and 1.55 g for pigs fed HP DDG, corn germ, and the P-free diet, respectively).

Pigs fed the corn germ diet had a lower ($P < 0.01$) ATTD of Ca (35%) compared with the ATTD of Ca from pigs fed the HP DDG (75%) or the P-free diet (76%). The ATTD and TTTD of P was greater ($P < 0.01$) in the HP DDG diet (59.6 and 69.3%,

respectively) than in the corn germ diet (28.6 and 33.7%, respectively). The basal endogenous loss of P was estimated from pigs fed the P-free diet at 211 ± 39 mg per kg DMI.

The absorption of Ca was lower ($P < 0.05$) in pigs fed the corn germ diet (1.18 g) than in pigs fed the HP DDG (2.55 g) or the P-free (1.99 g) diets. The retention of Ca was greater ($P < 0.05$) for the HP DDG diet (1.78 g) than for the corn germ (0.97 g) or the P-free (0.43 g) diets. When Ca retention was calculated as a percentage of Ca-intake, the HP DDG diet had the greatest ($P < 0.05$) retention (53%) when compared with the corn germ (29%) or the P-free (14%) diets.

The P absorption and P retention in g per d did not differ between the HP DDG and corn germ diets. When P retention was calculated as a percentage of P-intake, the HP DDG diet had a greater ($P < 0.01$) retention (58.9%) than the corn germ diet (26.7%).

Amino Acid Digestibility

The AID and SID for CP and AA in HP DDG and corn germ are presented in Table 3.9. The AID for CP and all AA except Arg and Pro were greater ($P < 0.05$) in HP DDG than in corn germ. Likewise, the SID for CP and all AA except Arg, Lys, Gly, and Pro were greater ($P < 0.05$) in HP DDG than in corn germ.

DISCUSSION

Energy Digestibility

The GE and CP in corn correspond with published values (Pedersen et al., 2007). These values were lower than in the HP DDG. When corn goes through fermentation,

the starch is converted to ethanol. Corn contains approximately 66% starch. Therefore, after fermentation the remaining nutrients (protein, fat, and fiber) are concentrated 3 times in DDGS compared with corn. When corn is de-hulled and de-germed before fermentation the resulting HP DDG has a greater CP, ADF, and NDF concentration than corn. In addition, HP DDG has a greater GE than corn. The higher fat content contributes to the greater DE and ME in HP DDG compared with corn.

When comparing published conventional DDGS values to HP DDG, it appears that HP DDG has a greater energy digestibility. Pedersen et al. (2007) reported an average GE of 5,398 kcal/kg DM in 10 samples of conventional DDGS, which is similar to the GE in HP DDG of 5,399 kcal/kg DM that was measured in the current experiment. However, the ATTD of GE was 76.8% for conventional DDGS (Pedersen et al., 2007), which is lower than the 88.2% that was measured for HP DDG in the present study. As a consequence, HP DDG has a greater DE and ME (4,763 and 4,476 kcal/kg DM, respectively) than previously published (Pedersen et al., 2007) for conventional DDGS (4,140 and 3,897 kcal/kg DM, respectively). The HP DDG has the hull removed before fermentation; therefore, it contains less ADF and NDF than conventional DDGS, which is the likely reason for the higher energy digestibility in the HP DDG than in conventional DDGS.

High-protein DDG and corn germ have similar GE values (5,399 and 5,335 kcal/kg DM, respectively); however, HP DDG has a greater ATTD of GE than corn germ. Therefore, DE and ME are greater in HP DDG than in corn germ. The reason for the lower ATTD in corn germ may be that corn germ contains more NDF (20.4%) than

HP DDG (16.4%). However, it is also likely that the fiber in HP DDG are more digestible than in corn germ because they have been fermented. If this is true then that would explain the increased ATTD for energy in HP DDG.

Corn germ has a greater GE than corn because of the greater concentration of fat. However, corn has a greater ATTD for GE than corn germ, and therefore, the DE and ME were not greater in corn germ than in corn. The increased concentration of ADF and NDF in corn germ compared with corn is likely the reason for the lower ATTD for GE in corn germ. It was not the objective of this experiment to measure the ATTD for ADF and NDF. However, based on the data for corn germ, it can be speculated that the fibers in corn germ have a low digestibility. Otherwise, corn germ containing 18% fat should have had a greater ATTD for GE.

Phosphorus Digestibility

The values for ATTD of P in HP DDG and corn germ that were measured in this experiment are similar to values measured in poultry (Parsons et al., 2006). The concentration of P in HP DDG and corn germ that was measured in this study also concurs with the values measured by Parsons et al. (2006).

Pedersen et al. (2007) reported an average P level of 0.61% in 10 samples of conventional DDGS, which is greater then the 0.37% found in HP DDG. The reason for the lower concentration of P in HP DDG is most likely that the corn was degermed prior to fermentation. However, HP DDG had a similar ATTD of P (59.6%) compared with conventional DDGS (59.1%). Corn germ contains much of the P in corn, which is the reason for the high concentration (1.09%) of P in corn germ. The P is also less digestible

in corn germ than in the HP DDG. Bohlke et al. (2005) reported a value of 28.8% for ATTD of P in corn, which is similar to the value of 28.6% found for corn germ in the present experiment. It therefore appears that corn germ and corn have similar P digestibility and HP DDG and conventional DDGS also have similar digestibility values for P. When corn goes through the fermentation process, some of the bonds that bind P to the phytate complex are hydrolyzed. Therefore, more P is available for absorption in the small intestine of the pig, which is likely the reason the ATTD for P in HP DDG and conventional DDGS are greater than in un-fermented corn and corn germ.

The endogenous losses of P were estimated at 211 ± 39 mg per kg DMI. This value is greater than the value of 138 mg per kg DMI that Petersen and Stein (2006) reported. However, in a study by Stein et al. (2006a), the endogenous loss of P was reported at 207 mg per kg DMI, which is in close agreement with the values obtained in this experiment. The values reported by Petersen and Stein (2006) and by Stein et al. (2006a) were measured using a P-free diet as was used in this study. Values for endogenous losses that were measured using the regression technique have been reported between 70 mg per kg DMI (Pettey et al., 2006) and 670 mg per kg DMI (Shen et al., 2002). Thus, the value for endogenous losses of P obtained in this experiment is within the wide range of previously published values.

Amino Acid Digestibility

The AID and SID for most AA and CP in HP DDG that were measured in this experiment are greater than values reported for conventional DDGS (Stein et al., 2006b). The reason for this observation is most likely that there are no solubles added to the HP

DDG as is the case for DDGS. It has been shown that in conventional DDGS production, greater AID and SID for AA are obtained if the solubles are not added to the DDG (Pahm, 2006, personal communication).

The relatively low values for AID and SID that were measured for corn germ indicate that the protein in the germ fraction is of poor quality. Another possible reason for the low AID and SID in corn germ is the greater concentration of ADF and NDF. It has been demonstrated that greater concentrations of fiber negatively influences AA digestibility (Mosenthin et al., 1994; Lenis et al., 1996). In addition, the nutritional value of corn germ can be greatly reduced by processing (Lawton et al., 2003).

IMPLICATION

High-protein distillers dried grains has a greater digestibility of energy and most amino acids than previously reported for conventional distillers dried grains with solubles and corn. The digestibility of phosphorus in high-protein distillers dried grains is similar to values previously reported for conventional distillers dried grains with solubles, but greater than in corn. Therefore, high-protein distillers dried grains is expected to have a greater feeding value than conventional distillers dried grains with solubles or corn when fed to pigs. Corn germ has a lower energy and amino acid digestibility than corn or conventional distillers dried grains with solubles. However, the digestible energy and metabolizable energy in corn germ is similar to corn.

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Table 3.1. Analyzed nutrient composition of ingredients (as-fed basis)

Item	Ingredients:	Corn[1]	HP DDG[2]	Corn germ
DM, %		88.00	92.40	92.20
CP, %		7.20	41.10	14.00
Starch, %		55.70	11.20	23.60
Crude fat, %		3.30	3.70	17.60
ADF, %		2.50	8.70	5.60
NDF, %		90	16.40	20.40
Ash, %		3.30	3.20	3.30
Ca, %		—	0.01	0.03
P, %		—	0.37	1.09
GE, kcal/kg		3,890	4,989	4,919
Indispensable AA (%)				
Arginine		—	1.54	1.08
Histidine		—	1.14	0.41
Isoleucine		—	1.75	0.45
Leucine		—	5.89	1.06
Lysine		—	1.23	0.79
Methionine		—	0.83	0.25
Phenylalanine		—	2.29	0.57
Threonine		—	1.52	0.51

Tryptophan	—	0.21	0.12
Valine	—	2.11	0.71
Dispensable AA (%)			
Alanine	—	3.17	0.91
Aspartic Acid	—	2.54	1.05
Cysteine	—	0.78	0.29
Glutamic Acid	—	7.11	1.83
Glycine	—	1.38	0.76
Proline	—	3.68	0.92
Serine	—	1.85	0.56
Tyrosine	—	1.91	0.41

[1]Amino acids, Ca, and P were not analyzed in corn.

[2]HP DDG = high-protein distillers dried grains.

Table 3.2. Ingredient composition of diets (as-fed basis), Exp. 1

Ingredients, % Diet:	Corn	HP DDG[1]	Corn germ
Corn	97.60	50.00	50.00
HP DDG[1]	-	47.70	-
Corn germ	-	-	47.80
Dicalcium phosphate	1.00	0.65	-
Limestone	0.80	1.05	1.60
Salt	0.40	0.40	0.40
Vitamin premix[2]	0.05	0.05	0.05
Micromineral premix[3]	0.15	0.15	0.15
Energy and CP (analyzed)			
GE, kcal/kg	3,798	4,347	4,305
CP, %	7.10	24.10	9.70

[1]HP DDG = high-protein distillers dried grains.

[2]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 10,990 IU as acetate; vitamin D_3, 1,648 IU as D-activated animal sterol; vitamin E, 55 IU as alpha tocopherol acetate; vitamin K_3, 4.4 mg as menadione dimethylpyrimidinol bisulphite; thiamin, 3.3 mg as thiamine mononitrate; riboflavin, 9.4 mg; pyridoxine, 3.3 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.044 mg; D-pantothenic acid, 33 mg as calcium pantothenate; niacin, 55 mg; folic acid, 1.1 mg; biotin, 0.17 mg.

[3]Provided the following quantities of micro minerals per kilogram of complete diet: Se, 0.18 mg as sodium selenite; I, 0.22 mg as potassium iodate; Cu, 9.5 mg as copper sulfate; Mn, 26.5 mg as manganese sulfate; Fe, 99 mg as iron sulfate; Zn, 99 mg as zinc oxide.

Table 3.3. Composition of diets (as-fed basis), Exp. 2

Ingredient, % Diet:	HP DDG[1]	Corn germ	P-free
HP DDG[1]	60.00	-	-
Corn germ	-	42.50	-
Sugar	15.00	15.00	20.00
Soybean oil	3.00	-	4.00
Gelatin	-	10.00	20.00
Solka floc[2]	-	-	4.00
Limestone	1.20	1.55	0.80
L-Lysine•HCl	0.24	0.06	-
DL-Methionine	-	0.02	0.27
L-Threonine	-	0.10	0.08
L-Tryptophan	0.01	-	0.14
L-Histidine	-	-	0.08
L-Isoleucine	-	-	0.16
L-Valine	-	-	0.05
Salt	0.40	0.40	0.40
Vitamin premix[3]	0.05	0.05	0.05
Micromineral premix[4]	0.15	0.15	0.15
Potassium carbonate	-	-	0.40
Magnesium oxide	-	-	0.10

Cornstarch	19.95	30.17	49.32
Nutrients (analyzed)			
Ca, %	0.38	0.44	0.26
P, %	0.23	0.50	-

[1]HP DDG = high-protein distillers dried grains.

[2]Fiber Sales and Development Corp., Urbana, OH.

[3]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 10,990 IU as acetate; vitamin D_3, 1,648 IU as D-activated animal sterol; vitamin E, 55 IU as alpha tocopherol acetate; vitamin K_3, 4.4 mg as menadione dimethylpyrimidinol bisulphite; thiamin, 3.3 mg as thiamine mononitrate; riboflavin, 9.4 mg; pyridoxine, 3.3 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.044 mg; D-pantothenic acid, 33 mg as calcium pantothenate; niacin, 55 mg; folic acid, 1.1 mg; biotin, 0.17 mg.

[4]Provided the following quantities of micro minerals per kilogram of complete diet: Se, 0.18 mg as sodium selenite; I, 0.22 mg as potassium iodate; Cu, 9.5 mg as copper sulfate; Mn, 26.5 mg as manganese sulfate; Fe, 99 mg as iron sulfate; Zn, 99 mg as zinc oxide.

Table 3.4. Ingredient composition of diets (as-fed basis), Exp. 3

Ingredient, % Diet:	HP DDG[1]	Corn germ	N-free
HP DDG[1]	50.00	-	-
Corn germ	-	50.00	-
Sugar	35.00	35.00	20.00
Soybean oil	3.00	3.00	3.00
Solka floc[2]	-	-	3.00
Chromic oxide	0.40	0.40	0.40
Dicalcium phosphate	1.65	-	2.75
Limestone	0.75	1.85	0.20
Salt	0.40	0.40	0.40
Vitamin premix[3]	0.05	0.05	0.05
Micromineral premix[4]	0.15	0.15	0.15
Potassium carbonate	-	-	0.40
Magnesium oxide	-	-	0.10
Cornstarch	8.60	9.15	69.55

[1]HP DDG = high-protein distillers dried grains.

[2]Fiber Sales and Development Corp., Urbana, OH.

[3]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 10,990 IU as acetate; vitamin D_3, 1,648 IU as D-activated animal sterol; vitamin E, 55 IU as alpha tocopherol acetate; vitamin K_3, 4.4 mg as menadione

dimethylpyrimidinol bisulphite; thiamin, 3.3 mg as thiamine mononitrate; riboflavin, 9.4 mg; pyridoxine, 3.3 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.044 mg; D-pantothenic acid, 33 mg as calcium pantothenate; niacin, 55 mg; folic acid, 1.1 mg; biotin, 0.17 mg.

[4]Provided the following quantities of micro minerals per kilogram of complete diet: Se, 0.18 mg as sodium selenite; I, 0.22 mg as potassium iodate; Cu, 9.5 mg as copper sulfate; Mn, 26.5 mg as manganese sulfate; Fe, 99 mg as iron sulfate; Zn, 99 mg as zinc oxide.

Table 3.5. Analyzed nutrient composition of diets (as-fed basis), Exp. 3

Item	Diet:	HP DDG[1]	Corn germ	N-Free
DM, %		94.90	95.30	92.40
CP, %		20.60	6.91	0.28
Indispensable AA (%)				
Arginine		0.74	0.51	-
Histidine		0.55	0.20	-
Isoleucine		0.83	0.22	-
Leucine		2.88	0.53	0.01
Lysine		0.61	0.37	0.01
Methionine		0.39	0.11	-
Phenylalanine		1.10	0.28	0.01
Threonine		0.76	0.26	-
Tryptophan		0.10	0.07	< 0.04
Valine		1.01	0.35	0.01
Dispensible AA (%)				
Alanine		1.58	0.45	0.01
Aspartic Acid		1.29	0.53	0.01
Cysteine		0.38	0.14	-
Glutamic Acid		3.71	0.95	0.02
Glycine		0.68	0.37	-

Proline	1.81	0.43	0.01
Serine	0.90	0.28	-
Tyrosine	0.85	0.20	-

[1]HP DDG = high-protein distillers dried grains.

Table 3.6. Daily energy and nitrogen balance in experimental diets (as fed basis)[1]

Item	Diet: Corn	HP DDG[2]	Corn germ	SEM	*P* - value
GE intake, kcal	5,391	5,789	5,915	492.3	0.551
N intake, g	18.7^{x}	57.7^{y}	23.9^{x}	3.09	< 0.001
GE in feces, kcal	533^{x}	682^{x}	1,109^{y}	57.1	< 0.001
GE in urine, kcal	90^{x}	219^{y}	119^{x}	24.1	0.004
N in feces, g	3.0^{x}	5.5^{y}	4.3^{y}	0.46	0.002
N in urine, g	7.6^{x}	23.3^{y}	8.2^{x}	2.48	< 0.001
DE in diet, kcal/kg, as is	3,402^{x}	3,843^{y}	3,497^{x}	32.8	< 0.001
Apparent total tract digestibility, GE, %	89.6^{y}	88.4^{y}	81.2^{x}	0.82	< 0.001
ME in diet, kcal/kg, as is	3,332^{x}	3,680^{y}	3,411^{x}	39.9	< 0.001
N absorbed, g	15.8^{x}	52.1^{y}	19.6^{x}	2.73	< 0.001
N retention, g	8.2^{x}	28.8^{y}	11.4^{x}	2.55	< 0.001
N, retention, %	37	51	48	8.3	0.503
Apparent total tract digestibility, N, %	82.7^{x}	90.6^{y}	81.9^{x}	1.73	0.005

[1]Data represent means of 6 observations per treatment.

[2] HP DDG = high protein distillers dried grains.

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

Table 3.7. Daily energy and nitrogen balance in corn, HP DDG[1], and corn germ (as fed basis)[2]

Item Ingredient:	Corn	HP DDG[1]	Corn germ	SEM	*P* - value
GE intake, kcal	5,523[y]	3,027[x]	3,154[x]	590.9	< 0.001
N intake, g	19.2[x]	48.1[y]	14.3[x]	3.11	< 0.001
GE in feces, kcal	546[x]	409[x]	836[y]	59.1	< 0.001
GE in urine, kcal	92[x]	173[y]	73[x]	22.0	0.013
N in feces, g	3.1	4.0	2.8	0.46	0.115
N in urine, g	7.8[x]	19.5[y]	4.3[x]	2.48	0.002
DE, ingredient, kcal/kg, as-is	3,486[x]	4,403[y]	3,670[x]	62.3	< 0.001
DE, ingredient, kcal/kg DM	4,056[x]	4,763[y]	3,979[x]	68.3	< 0.001
Apparent total tract digestibility, GE, %	89.6[y]	88.2[y]	74.6[x]	1.32	< 0.001
ME, ingredient, kcal/kg, as-is	3,414[x]	4,137[y]	3,566[x]	69.8	< 0.001
ME, ingredient, kcal/kg, DM	3,972[x]	4,476[y]	3,866[x]	76.9	< 0.001
N absorbed, g	16.1[x]	44.1[y]	11.5[x]	2.75	< 0.001
N retention, g	8.4[x]	24.6[y]	7.2[x]	2.58	< 0.001
N, retention, %	37	53	51	8.7	0.426
Apparent total tract digestibility, N, %	82.7[x]	92.0[y]	80.3[x]	1.86	< 0.001

[1] HP DDG = high-protein distillers dried grains.

[1]Data represent means of 6 observations per treatment.

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

Table 3.8. Daily balance and apparent (ATTD) and true (TTTD) total tract digestibility of P in HP DDG[1] and corn germ[2]

Item	HP DDG[1]	Corn germ	P-free	SEM	*P* - value
Feed intake, g, DM	825[y]	671[x]	900[y]	49.7	0.012
Ca intake, g	3.38[y]	3.37[y]	2.58[x]	0.169	0.003
P intake, g	2.09[x]	3.82[y]	-	0.107	< 0.001
Ca in feces, g	0.83[x]	2.19[y]	0.59[x]	0.146	< 0.001
P in feces, g	0.82[y]	2.74[z]	0.19[x]	0.099	< 0.001
Ca in urine, g	0.77[y]	0.21[x]	1.55[z]	0.095	< 0.001
P in urine, g	0.02[x]	0.07[y]	0.01[x]	0.015	0.018
ATTD, Ca, %	75[y]	35[x]	76[y]	5.1	< 0.001
ATTD, P, %	59.6[y]	28.6[x]	-	2.63	< 0.001
TTTD, P, %[3]	69.3[y]	33.7[x]	-	2.52	< 0.001
Ca absorption, g	2.55[y]	1.18[x]	1.99[y]	0.210	< 0.001
P absorption, g	1.27	1.09	-	0.106	0.231
Ca retention, g	1.78[y]	0.97[x]	0.43[x]	0.226	< 0.001
P retention, g	1.26	1.02	-	0.106	0.126
Ca, retention, %	53[y]	29[x]	14[x]	7.1	0.003
P, retention, %	58.9[y]	26.7[x]	-	2.62	< 0.001

[1]HP DDG = high-protein distillers dried grains.

[2]Data represent means of 10 observations per treatment.

[3]Values were calculated by correcting ATTD for the basal endogenous loss (211 mg per kg of DMI) that was calculated for pigs fed the P-free diet.

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

Table 3.9. Apparent (AID) and standardized (SID) ileal digestibility (%) of CP and AA in HP DDG[1] and corn germ by growing pigs, Exp. 3[2, 3, 4]

Procedure:	AID				SID			
Item Diet:	HP DDG[1]	Corn germ	SEM	*P*-value	HP DDG[1]	Corn germ	SEM	*P*-value
CP	72	33	3.2	0.001	80	56	4.1	0.007
Indispensable AA								
Arginine	75	73	1.8	0.095	83	83	1.8	0.693
Histidine	78	60	2.0	0.001	81	69	2.1	0.004
Isoleucine	77	44	2.8	0.001	81	57	3.2	0.002
Leucine	89	58	1.9	0.001	91	68	2.1	0.001
Lysine	57	47	2.9	0.025	64	58	3.0	0.152
Methionine	86	61	2.3	0.001	88	68	2.5	0.001
Phenylalanine	85	53	2.4	0.001	87	64	2.6	0.001
Threonine	70	34	4.0	0.001	77	53	4.7	0.010
Tryptophan	71	53	4.4	0.033	81	67	4.1	0.042

Valine	76	49	2.3	0.001	80	62	2.7	0.003
Dispensable AA								
Alanine	83	53	2.4	0.001	86	64	2.8	0.002
Aspartic acid	70	47	3.1	0.002	76	60	3.6	0.018
Cysteine	78	52	2.4	0.001	82	64	2.7	0.001
Glutamic acid	86	63	2.0	0.001	88	72	2.3	0.003
Glycine	44	14	6.1	0.001	75	76	10.7	0.924
Proline	46	-34	22.0	0.100	73	84	8.4	0.292
Serine	79	48	1.7	0.001	84	65	2.2	0.001
Tyrosine	85	46	3.3	0.001	88	59	3.6	0.002

[1]HP DDG = high-protein distillers dried grains.

[2]AID = {100 – [(CP or AA in digesta DM/CP or AA in feed DM) x (chromium in feed DM/chromium in digesta DM)]} x 100%.

[3]SID = [AID + (endogenous losses/intake)] x 100%. Endogenous losses determined after feeding the N-free diet (g per kg DMI): CP, 16.6; Arg, 0.61; His, 0.17; Ile, 0.28; Leu, 0.47; Lys, 0.40; Met, 0.07; Phe, 0.29; Thr, 0.47; Trp, 0.10; Val, 0.42; Ala, 0.53; Asp, 0.72; Cys, 0.16; Glu, 0.87; Gly, 2.15; Pro, 5.97; Ser, 0.47; Tyr, 0.26.

[4]Data are least square means of 6 observations per treatment.

CHAPTER 4

Effects of co-products from the ethanol industry on pig performance, carcass composition, and the palatability of pork

ABSTRACT: An experiment was conducted to investigate pig performance, carcass composition, and palatability of pork from pigs fed distillers dried grains with solubles (DDGS), high-protein distillers dried grains (HP DDG), and corn germ. Eighty-four pigs (initial BW: 22 kg ± 1.7 kg) were allotted to 1 of 7 dietary treatments with 6 replicates per treatment and 2 pigs per pen. Diets were fed for 114 d in a 3-phase sequence. The control diet sequence was based on corn and soybean meal. Two sequences were formulated using 10 or 20% DDGS in each phase. Two additional sequences contained HP DDG in amounts sufficient to substitute either 50 or 100% of the soybean meal used in the control sequence. The last 2 sequences contained 5 or 10% corn germ, which was calculated to provide the same amount of fat as the 10 or 20% DDGS diets, respectively. Results of the experiment showed that for the entire experiment, pig performance was not affected by the inclusion of DDGS or HP DDG in the diet. However, final BW increased (linear, $P < 0.05$) as corn germ was included in the diet. Carcass composition and muscle quality were not influenced overall by the addition of DDGS to the diets. However, LM area and LM depth decreased (linear, $P < 0.05$) as HP DDG was added to the diet. In addition, lean meat percent increased and drip loss decreased as corn germ was included in the diets (quadratic, $P < 0.05$). There was no effect of DDGS on fat quality with the

exception of a decrease (linear, $P < 0.05$) in belly firmness score as DDGS concentration increased. Including HP DDG or corn germ in the diets did not affect fat quality except iodine value increased (linear, $P < 0.05$) in HP DDG diets and decreased (linear, $P < 0.05$) in corn germ diets as inclusion levels increased. Cooking loss, shear force, and bacon distortion score were not affected by the inclusion of DDGS, HP DDG, or corn germ in the diet. Overall, the palatability of bacon and pork chops was not affected by dietary treatment. In conclusion, feeding 20% DDGS and high levels of HP DDG to grow-finish pigs did not negatively affect overall pig performance, carcass composition, muscle quality, or palatability but may decrease fat quality. Feeding up to 10% corn germ did not negatively affect pig performance, carcass composition, carcass quality, or pork palatability but increased final BW of pigs and reduced iodine value of belly fat.

Key words: Corn germ, distillers dried grains with solubles, high-protein distillers dried grains, palatability, performance, pigs

INTRODUCTION

The ethanol industry in the Midwest continues to grow and is expected to double during the next 6 years, which will produce 12 to 14 million metric tons of co-product (Renewable Fuels Association, 2006). This co-product, distillers dried grains with solubles (**DDGS**), is usually fed to livestock. The energy, P, and AA digestibility of DDGS fed to swine has been reported (Fastinger and Mahan, 2006; Stein et al., 2006;

Pedersen et al., 2007). Growth performance and carcass characteristics have been reported in growing-finishing pigs that have been fed different concentrations of DDGS (Whitney et al., 2006), but no data are available on the palatability of pork fed diets containing DDGS.

Dakota Gold Marketing (Sioux Falls, SD) has introduced a new bio-refining ethanol technology called BFrac™. This new process de-hulls and de-germs the corn prior to fermentation and increases the ethanol yield from the starch fraction of the corn. Two new co-products are produced from this process. These 2 co-products are corn germ, originating from de-germing of the corn, and high-protein distillers dried grains (**HP DDG**), which is the distillers dried grains **(DDG)** produced after the de-hulled and de-germed corn has been fermented. The digestibility of AA, P, and energy in these 2 products has recently been measured (Widmer et al., 2007). However, there is no information on the influence of these 2 products on pig performance, carcass quality, or palatability of pork obtained from pigs fed these products.

Therefore, the objective of this experiment was to evaluate the performance, carcass composition, pork quality, and pork palatability of pigs fed diets based on DDGS, HP DDG, or corn germ.

MATERIALS AND METHODS

Animals and Housing

Eighty-four growing pigs (initial BW: 22.1 kg ± 1.7 kg) originating from the matings of SP-1 boars to Line 13 sows (Ausgene Intl. Inc., Gridley IL) were allotted to 7

experimental groups based on BW, ancestry, and gender in a randomized complete block design. Pigs were housed in an environmentally controlled building with 1 barrow and 1 gilt in each pen and 6 replicate pens per treatment group. Treatments were randomized within the building and the experiment was conducted from June to November, 2006 with 2 replicates started on 3 different d. There were 2 weeks between the first 2 start d and 3 weeks between the last 2 start d. Pens were 1.2 × 2.4 m and had fully slatted concrete floors. A 1-hole feeder and a nipple drinker were installed in each pen. The Institutional Animal Care and Use Committee at South Dakota State University reviewed and approved the protocol for the experiment (#06-A030).

Diets, Feeding, and Live Data Recording

Conventional DDGS, corn germ, and HP DDG were obtained from Dakota Gold Marketing, Sioux Falls, SD. Commercial sources of corn and soybean meal were also used (Table 4.1 and 4.2). Pigs were fed their respective diets in a 3-phase sequence, with a grower diet being provided during the initial 46 d of the experiment, an early finisher diet during the next 40 d, and a late finisher diet during the remaining 28 d. Within each phase, 7 different diets (Tables 4.3, 4.4, and 4.5) were formulated. The control sequence was based on corn and soybean meal in all 3 phases. Two additional sequences were formulated using 10 or 20% conventional DDGS in each phase. Likewise, 2 sequences were formulated that contained HP DDG in amounts sufficient to substitute either 50 or 100% of the soybean meal used in the control sequence. The inclusion rates of HP DDG in the 50% replacement of soybean meal were 20, 15, and 10% for the grower, early finisher, and late finisher phases, respectively. The inclusion rates of HP DDG in the

100% replacement of soybean meal were 40, 30, and 20% for the grower, early finisher, and late finisher phase, respectively. The last 2 sequences were formulated using 5 or 10% corn germ in all 3 phases. The amount of fat provided by corn germ in these 2 diets were calculated to be equal to the amounts of fat provided by DDGS in the diets containing 10 and 20% DDGS, respectively. All diets were formulated based on standardized ileal digestibility (**SID**) of AA and apparent total tract digestibility (**ATTD**) of P. Diets were formulated to contain 0.83% SID Lys and 0.23% ATTD P in the grower phase, 0.67% SID Lys and 0.19% ATTD P in the early finishing phase and 0.52% SID Lys and 0.15% ATTD P in the late finishing phase. Concentrations of DE and ME were allowed to vary among diets. Digestibility values for AA, P, and energy in corn and soybean meal were from NRC (1998), but for conventional DDGS, values were obtained from Stein et al. (2006) and Pedersen et al. (2007). Digestibility values for energy and nutrients in HP DDG and corn germ were from Widmer et al. (2007). Vitamins and minerals were included in all diets to meet or exceed estimated nutrient requirements for growing and finishing pigs (NRC, 1998). Pigs had ad libitum access to feed and water throughout the experiment.

Individual pig weights were recorded at the beginning of the experiment and at the end of each phase. Feed allotment to each pen was recorded daily, and feed in the feeders was weighed each time pigs were weighed. At the end of the experiment, ADFI, ADG, and G:F were calculated for each pen and phase and for the entire experimental period.

Chemical Analysis

All samples were analyzed in duplicate. Diets and feed ingredients were analyzed for DM (procedure 930.15; AOAC, 2005), CP (procedure 984.13; AOAC, 2005), crude fat (procedure 920.39; AOAC, 2005), P (procedure 946.06; AOAC, 2005), and Ca (procedure 935.13; AOAC, 2005). Amino acids were analyzed in all diets and feed ingredients on a Beckman 6300 Amino Acid Analyzer (Beckman Instruments Corp., Palo Alto, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Before analysis, samples were hydrolyzed with 6 *N* HCL for 24 h at 110°C (procedure 994.12, alt. 3; AOAC, 2005). Methionine and Cys were determined as Met sulfone and cysteic acid after cold performic acid oxidation and acid hydrolysis (procedure 994.12, alt. 1; AOAC, 2005). Tryptophan was determined after hydrolysis with NaOH for 22 h at 110°C (procedure 988.15, alt. 1; AOAC, 2005).

Carcass Evaluation

Pigs were harvested on 3 different d in the same order as they were started on the experiment and all replications were fed experimental diets for 114 d. Final pig BW and feed left in the feeders were recorded the afternoon before pigs were harvested. This weight was used to calculate data for ADFI, ADG, and G:F. Pigs were then taken off feed and fasted over night. The next morning, pigs were transported approximately 3 km to the South Dakota State University Meats Laboratory where they were harvested within 6 h after arrival in a randomized order among treatments.

Pigs were electrically stunned to render them unconscious prior to exsanguination. All slaughter procedures were conducted using standard procedures and

were in compliance with South Dakota State Meat Inspection. Carcasses were placed in the chiller approximately 45 min after stunning. The left side of each carcass was ribbed between the 10th and 11th rib 24 h postmortem and LM area, LM depth, and fat thickness was measured at the 10th rib using standard procedures (NPB, 2000). The lean meat percentage for each pig was also calculated (NPB, 2000).

The LM was removed without fat from the left side of each carcass. A 10 g LM sample (trimmed of fat and connective tissue) was homogenized with 90 mL of distilled water using a Janke & Kunkel Blender Ultra Turrax T25 (IKA Laborechnik, Staufen, W. Germany). Ultimate LM pH was measured using a PerPHecT LogR pH Meter Model 330 (Thermo Orion, Beverly, MA) and a Corning pH Electrode Model 476286 (Corning Incorporated, Corning, NY). A 2.54-cm thick chop was cut from the LM starting at the 11th rib and continuing toward the caudal end. The chop was weighed to the nearest 0.01 g, placed on a white Styrofoam tray, and retail wrapped (Koch Supplies, Kansas City, MO). All chops were placed at an approximate 30-degree angle in a 1 to 2°C cooler. After 48 h, each chop was removed from the package, patted dry with a paper towel, and weighed again to the nearest 0.01 g. Drip loss was determined as the percentage disappearance of initial weight.

Following removal of the chop used for drip loss measurement, the remainder of the loin, from the 11th rib location to the caudal end, was weighed to the nearest 4.5 g, vacuum packaged, and stored at 1 to 2°C. After 7 d, the LM was removed from the vacuum package bag, patted dry with a paper towel, and weighed to the nearest 4.5 g. Purge loss was determined as the percentage disappearance of initial weight. Four 2.54-

cm-thick chops were removed from the cranial end of the LM after purge loss was measured and stored at -20°C for shear force testing and palatability tests.

Belly firmness was measured on all belly primals with the spareribs removed. Belly firmness test consisted of measuring the belly length on a flat surface and then placing it skin-side down on a stainless steel smoke stick. The distance between the 2 ends of the suspended belly was measured. Belly firmness was calculated using Eq. [1] (Whitney et al., 2006):

$$\text{Belly Firmness} = \cos^{-1}\{[0.5(L^2) - D^2]/[0.5(L^2)]\} \quad [1]$$

where L is the belly length measured on a flat surface and D is the distance between the 2 ends of a suspended belly. Belly thickness was measured by placing a probe at the scribe line half way between the cranial and caudal ends. The belly firmness score was adjusted by the belly thickness measurement. Belly temperature was measured immediately prior to the belly firmness test. Fat samples for analysis of iodine values were taken midway between the cranial and caudal ends of the belly at a point just dorsal to the scribe line. Belly's were frozen for palatability testing at a later date.

Subjective color and marbling scores of the LM were obtained following a 15-min bloom time according to the National Pork Producers Council Quality Standards (NPPC, 1999). Values for L*, a*, and b* color of the LM were measured using a Minolta Chroma Meter CR-310 (Minolta Corp., Ramsey, NJ) at D_{65} illuminant calibrated to a white plate. An area just cranial of the 10^{th} rib was skinned to obtain L*, a*, and b* color values for the 2^{nd} layer of fat, counting from the skin inward.

Palatability

Two 2.54 cm thick chops for shear force measurements were removed from the -20°C storage and allowed to thaw for 24 h at 1.4°C. The chops were then cooked at 218° C for 6 minutes or until they reached an internal temperature of 71°C in an impingement oven (Lincoln Foodservice Products Inc., Ft. Wayne, IN). The chops were weighed raw (before cooking) and again after cooking to the nearest 0.01 g. Cooking loss was determined and expressed as a percentage of initial raw weight. After chops cooled to room temperature, three 1.27-cm diameter cores were taken from each chop (6 cores per pig) parallel to the muscle fiber orientation. Peak shear force was measured, once for each core, using a Warner-Bratzler shear force machine (G-R Electric Manufacturing Company, Manhattan, KS).

Bellies were allowed to thaw and were injected with a brine that consisted of 0.907 kg of a commercial bacon cure per 3.785 L of water. The bellies were pumped to 112% of starting weight using an Inject Star injector Model BI-72 (Inject Star of the Americas, Inc., Brookfield, CT). The bellies were then smoked in a Fessmann single truck smokehouse (Fessmann LP, Kansas City, MO) for approximately 5 h with the smokehouse schedule consisting of the following steps: Step 1 was 20 min on high smoke with the dry bulb temperature at 54.4°C and with 0% humidity. Step 2 was 3 h and 40 min on low smoke with the dry bulb temperature at 57.2°C and with 34% humidity. Step 3 lasted until the bellies reached an internal temperature of 53.3°C on low smoke with a dry bulb temperature of 65.6°C and with 54% humidity. The bellies were then removed from the smokehouse and placed in a 1.4°C cooler to cool overnight. The

bellies were sliced and 8 slices were selected from approximately the middle of the belly and were vacuum packaged and placed in a 1.4°C cooler until taste panels were conducted.

An 8-member trained sensory panel evaluated the palatability of bacon and pork LM chops according to published guidelines (AMAS, 1995). Fifteen samples were evaluated per session, and 2 sessions were held per d. A nonexperimental warm up sample was used to initiate each session. Panelists were secluded in partitioned booths under red incandescent lights.

Bacon slices were cooked using a microwave oven to yield 37.5% of the slice's raw weight. Initial testing was conducted to determine the length of time that was required to cook the bacon to yield 37.5% of the raw weight. After cooking, a distortion score for each slice was given on a 5-point scale (5 = the most distortion and 1 = the least distortion) according to Mandigo (2002). The samples were stored in a 50°C warming oven until served. All panelists received half of a slice of bacon. The panel evaluated crispiness, tenderness, and bacon flavor intensity on an 8-point scale (8 = extremely crispy, extremely tender, or extremely intense and 1 = extremely soft, extremely tough, or extremely bland). The panel also evaluated fattiness, rancid flavor, piggy flavor, or fishy flavor on a 5-point scale (5 = extremely fatty, extremely rancid, extremely piggy, or extremely fishy and 1 = not fatty, not rancid, not piggy, or not fishy).

Two pork LM chops (2.54-cm thick) per pig were cooked on a clamshell-style grill (Model G12385IL, Foreman Champion & Burger, Columbia, MO) to an internal temperature of 71°C. They were cut into 1.3 × 2.5-cm cubes using a template and placed

into a warmed glass bowl. The samples were stored in a 50°C warming oven until served. The panel evaluated tenderness, juiciness, and pork flavor intensity on an 8-point scale (8 = extremely tender, extremely juicy, and extremely intense, 1 = extremely tough, extremely dry, and extremely bland). The panel also evaluated off-flavor intensity on a 4-point scale (1 = no off-flavor and 4 = extreme off-flavor). In addition, each panelist noted the off-flavor found.

Statistical Analysis

Growth performance data were analyzed using the PROC MIXED procedure (Littell et al., 1996) in SAS (SAS Stat. Inst., Cary, NC). Homogeneity of the data was verified using the UNIVARIATE procedure of SAS. The residual vs. predicted plot procedure was used to analyze data for outliers (greater than 2 times the standard deviation). Treatment means were calculated using the LSMEANS statement in PROC MIXED. Orthogonal polynomials were used to determine linear and quadratic effects of dietary DDGS, HP DDG, and corn germ concentrations. In addition, DDGS was also compared with corn germ and with HP DDG using orthogonal contrasts. The pen was the experimental unit and an alpha level of 0.05 was used to assess significance among means.

Data for carcass composition, muscle quality, and fat quality were also analyzed using the PROC MIXED procedure in SAS. Homogeneity of the data was verified using the UNIVARIATE procedure of SAS and the residual vs. predicted plot procedure was used to analyze data for outliers. Treatment means were calculated using the LSMEANS statement in PROC MIXED. In the initial model, the effects of treatment, gender, and

the interaction between treatment and gender were analyzed. However, there were no significant interactions between gender and treatment. Therefore, in the final model, this interaction was not included. Orthogonal polynomials were used to determine linear and quadratic effects of dietary DDGS, HP DDG, and corn germ concentrations. Belly firmness was adjusted by using belly thickness as a covariate. Data for DDGS were also compared to data for corn germ and HP DDG using orthogonal contrasts. The pig was the experimental unit and an alpha level of 0.05 was used to assess significance among means.

Data for bacon and pork chop palatability were analyzed as described for carcass composition, muscle quality, and fat quality. However, there was a significant interaction between treatment and gender for some parameters; therefore, the interaction term was left in the model. When an interaction occurred, data for both genders were reported.

RESULTS

Pig Performance

One pig on the HP DDG diet became sick 10 d into the trial and was removed from the study. All other pigs remained healthy throughout the experiment. There was no difference in initial BW among dietary treatments (Table 4.9).

There was no difference in ADG, ADFI, G:F, and final BW in either phase or for the entire experimental period among pigs fed the control, 10% DDGS, and 20% DDGS diets with the exception that G:F in the late finishing period decreased at 10% inclusion

of DDGS and then increased at 20% inclusion (quadratic, $P < 0.05$). In the early finisher phase, a trend (quadratic, $P = 0.06$) for an increase in ADG and final BW was observed as DDGS was included in the diet.

In the grower phase, ADG, ADFI, and final BW decreased (linear, $P < 0.05$) as the level of HP DDG was increased in the diet. A trend (linear, $P = 0.10$) for a decrease in G:F was also observed as HP DDG was included in the diets. No differences were found in ADG, ADFI, G:F, and final BW in the early finisher, late finisher, or for the entire experimental period among pigs fed the control diet and the 2 HP DDG containing diets. However, a trend (linear, $P = 0.07$) for a decrease in final BW in the early finisher phase and in ADFI for the entire experimental period was observed. Likewise, a trend (quadratic, $P = 0.06$) for a decrease in G:F was observed in the early and late finisher phases.

No differences were observed among pigs fed the control, 5% corn germ, and 10% corn germ diets for ADFI or G:F in either phase or for the entire experimental period. However, ADG in the early finisher phase and final BW increased as corn germ was added to the diets (linear, $P < 0.05$). A trend for a linear decrease in G:F in the grower phase ($P = 0.06$) and for a linear increase in final BW in the early finisher phase ($P = 0.08$) was also observed as corn germ was included in the diet. There was also a trend (linear, $P = 0.09$) for pigs to increase ADFI in the late finishing phase as corn germ was increased in the diet, and ADG for the entire experimental period tended (linear, $P = 0.06$) to increase as corn germ was added to the diet.

There was no difference between pigs fed the corn germ and DDGS diets for ADG, ADFI, G:F, and final BW in either phase or for the entire experimental period. However, ADG was lower ($P < 0.05$) for pigs fed HP DDG diets compared with pigs fed the DDGS diets in the grower phase and for the entire experimental period. In the grower phase, early finisher phase, and the entire experimental period, ADFI was greater ($P < 0.05$) for pigs fed the DDGS diets than for pigs fed the HP DDG diets, but G:F was greater ($P < 0.05$) for pigs fed the HP DDG diets in the early finisher phase than for pigs fed the DDGS diets. In the grower and early finisher phases, final BW was greater ($P < 0.05$) for pigs fed the DDGS diets than for pigs fed the HP DDG diets.

Carcass Composition

Hot carcass weight, dressing percentage, and carcass composition were not influenced by the addition of DDGS to the diets with the exception that a trend for an increase in last rib backfat (quadratic, $P < 0.08$) was observed (Table 4.10). Likewise, there was no effect of including HP DDG in diets for HCW, dressing percent, lean meat percent, 10^{th} rib backfat, last lumbar backfat, and last rib backfat. However, there was a decrease (linear, $P < 0.05$) in LM area, LM depth, and an increase (linear, $P < 0.05$) in 1^{st} rib backfat as HP DDG was added to the diet.

Hot carcass weight, dressing percent, LM area, LM depth, and last rib backfat were not influenced by the inclusion of corn germ in the diets. However, there was an increase (linear, $P < 0.05$) in last lumbar and first rib backfat as more corn germ was added to the diet. There was also an increase in lean meat percent and a decrease in 10^{th} rib backfat as corn germ was included in the diets (quadratic, $P < 0.05$).

There were no differences observed between pigs fed HP DDG and DDGS for any carcass composition traits. Likewise, no differences were observed between pigs fed DDGS and corn germ diets with the exception that LM area was greater ($P < 0.05$) for pigs fed corn germ diets than for pigs fed DDGS diets (49.52 vs. 44.80 cm^2, respectively).

No interactions between diets and gender were observed for carcass composition. Barrows had a greater ($P < 0.05$) final BW, dressing percentage, 10^{th} rib backfat, but a lower ($P < 0.05$) lean meat percentage than gilts (data not shown).

Muscle and Fat Quality

For LM marbling, color, L*, a*, drip loss, and purge loss, no effects of including DDGS in the diets were observed (Table 4.11). There was a decrease (linear, $P < 0.05$) in LM b* color as the concentration of DDGS in the diet increased and there was a trend (linear, $P = 0.09$) for an increase in LM pH as the concentration of DDGS increased. Longissimus muscle marbling, color, L*, a*, pH, and drip loss were not affected by the inclusion of HP DDG in the diets. However, there was a decrease (linear, $P < 0.05$) in LM b* color as HP DDG was added to the diet. In addition, there was a trend for an increase in purge loss as HP DDG was included in the diets (quadratic, $P = 0.09$). There was no effect of corn germ on LM marbling, color, L*, a*, pH, and purge loss. However, drip loss decreased at 5% corn germ in the diet, but increased at 10% inclusion of corn germ (quadratic, $P < 0.05$). There was also a trend for a decrease in LM b* as corn germ was included in the diet (quadratic $P = 0.05$).

No differences were found when DDGS was compared to either HP DDG or corn germ in any muscle quality traits. No interaction between diets and gender were observed for muscle quality. Values for LM color a* and b* were greater ($P < 0.05$) in barrows than in gilts but for all other values on muscle quality, no differences between the 2 genders were observed (data not shown).

There was no effect of DDGS on fat a*, belly thickness, belly temperature, or iodine value. However, belly firmness score and adjusted belly firmness score decreased as DDGS was added to the diet (linear, $P < 0.05$). Likewise, a trend for a decrease in fat L* was observed as DDGS was added to the diet (linear and quadratic, $P = 0.06$ and 0.07). Fat color (L*, a*, and b*) and belly thickness were not affected by the inclusion of HP DDG in the diets. However, iodine value increased ($P < 0.05$) and belly temperature decreased (quadratic, $P < 0.05$) as HP DDG was included in the diets. In addition, a trend (linear, $P = 0.06$) for decrease in belly firmness score and adjusted belly firmness score was observed as HP DDG was included in the diet. There was no effect of corn germ on fat color (L*, a*, and b*), belly thickness, belly firmness score, adjusted belly firmness score, and belly temperature. However, iodine value decreased as corn germ was added to the diet (linear and quadratic, $P < 0.05$). There was no difference between the HP DDG and DDGS diets in fat quality and there was no differences ($P < 0.05$) observed between the DDGS and corn germ diets with the exception that iodine value was lower ($P < 0.05$) for corn germ diets than for DDGS diets (67.3 vs. 70.9, respectively).

No interaction between diets and gender were observed for fat quality. The value for fat L* was greater ($P < 0.001$) for barrows than for gilts, but values for a* and b* were greater ($P < 0.001$) for gilts than for barrows (Table 4.12). Belly thickness and belly firmness but not the adjusted belly firmness were also greater ($P < 0.001$) for barrows than for gilts. In contrast, gilts had greater ($P < 0.001$) iodine values than barrows (73.2 vs. 67.8).

Palatability

Cooking loss, shear force, and bacon distortion were not influenced by the addition of HP DDG or corn germ to the diets (Table 4.13). However, there was a tendency for a linear decrease in cooking loss ($P = 0.09$) and in bacon distortion ($P = 0.07$) as DDGS was added to the diet.

The trained taste panelists did not detect any differences in bacon flavor intensity, piggy taste, or fishy taste among the control, 10% DDGS, or 20% DDGS diets. However, there was a decrease in bacon tenderness as DDGS was added to the diet (linear and quadratic, $P < 0.05$) and there was a trend for an increase in bacon crispiness as DDGS was included in the diet (quadratic, $P = 0.07$). In contrast, there was a trend for a decrease in bacon fattiness and rancid taste as DDGS was added to the diet (linear, $P = 0.06$ and 0.07, respectively).

Bacon crispiness, tenderness, flavor intensity, rancid taste, piggy taste, and fishy taste were not affected by the inclusion of HP DDG in the diets. However, there was a trend for an increase in bacon fattiness taste as HP DDG was added to the diet (quadratic, $P = 0.08$)

There was no effect of corn germ on bacon crispiness, flavor intensity, fattiness taste, piggy taste, or fishy taste. There was a trend (quadratic, $P = 0.08$) for an increase in bacon tenderness as the concentration of corn germ in the diet increased and there was a trend (linear, $P = 0.08$) for a decrease in rancid taste as the concentration of corn germ increased.

There was a diet × gender interaction ($P < 0.05$) of DDGS inclusion levels on pork chop tenderness and juiciness. Barrows had an increase in pork chop tenderness (quadratic, $P < 0.05$) and juiciness (linear, $P < 0.05$) as DDGS was added to the diet. However, gilts had a decrease in pork chop tenderness, juiciness, and flavor intensity (linear, $P < 0.05$) as the concentration of DDGS increased in the diet. There was no effect of DDGS on pork chop piggy taste, other off flavors, and total off flavors. However, there was a decrease (quadratic, $P < 0.05$ and linear, $P = 0.06$) in pork chop metallic taste as the concentration of DDGS in the diet increased and there was a trend for a decrease in pork chop off flavor intensity as the concentration of DDGS increased (linear, $P = 0.09$).

A diet × gender interaction ($P < 0.05$) for pork chop juiciness and flavor intensity was observed as HP DDG inclusion increased. There was an increase (linear, $P < 0.05$) in barrow pork chop juiciness as the concentration of HP DDG in the diet increased and there was a trend (linear, $P = 0.07$) for an increase in barrow pork chop tenderness and flavor intensity as the concentration of HP DDG increased in the diet. In contrast, there was a decrease in gilt pork chop flavor intensity as HP DDG was included in the diet (quadratic, $P < 0.05$). Pork chop off flavor intensity, piggy taste, other off flavors, and

total off flavors were not influenced by the inclusion of HP DDG in the diets. However, there was a trend for a decrease in pork chop metallic taste as HP DDG was added to the diet (linear, $P < 0.09$).

There was a diet × gender interaction ($P < 0.05$) for pork chop juiciness as dietary corn germ inclusion increased. There was no difference between barrows or gilts for pork chop tenderness or juiciness. However, there was a trend for an increase in pork chop flavor intensity for gilts as inclusion of corn germ increased (linear, $P = 0.08$), but this was not the case for barrows. Pork chop off flavor intensity, metallic taste, piggy taste, other off flavors, and total off flavors were not influenced by the inclusion of corn germ in the diets.

DISCUSSION

The concentration of CP, crude fat, P, and AA in corn and DDGS correspond with published values (Stein et al., 2006; Pedersen et al., 2007) and concentrations of CP, crude fat, Ca, P, and AA in HP DDG and corn germ are consistent with values reported by Widmer et al. (2007). Corn and DDGS had similar fatty acid composition as would be expected because DDGS is produced from fermented corn. When corn goes through fermentation, starch is converted to ethanol and the fatty acids remain the same. This observation shows that fatty acids are not hydrogenated during fermentation of the corn. The fatty acid profile of HP DDG is also similar to DDGS, but corn germ has a greater concentration of linoleic acid and a lower concentration of saturated fatty acids than DDGS, HP DDG, and corn. This observation is consistent with the profile reported for

corn germ meal expeller (INRA-AFZ-INAPG, 2004). Soybean meal has a greater concentration of linolenic acid than corn, which corresponds with published values (INRA-AFZ-INAPG, 2004).

Pig Performance

Growth performance was not affected by the addition of 10 or 20% DDGS to grow-finish diets, which corresponds with Cook et al. (2005) and DeDecker et al. (2005) who reported that the inclusion of up to 30% DDGS in diets fed to growing-finishing pigs had no influence on pig performance. However, Fu et al., (2004), Linneen et al. (2006), and Whitney et al. (2006) found a decrease in pig performance as DDGS concentration increased in the diet. One possible reason for these conflicting observations may be that different qualities of DDGS were used. The digestibility of AA and energy varies among sources of DDGS (Fastinger and Mahan, 2006; Stein et al., 2006). In addition, the diets in the present experiment were formulated based on SID AA, whereas the diets used in the experiments by Fu et al. (2004), Linneen et al. (2006), and Whitney et al. (2006) were formulated based on concentrations of total AA. Crystalline Lys was also added in greater concentrations as DDGS was included in the diets and more SBM was removed in this experiment than in previous experiments (Linneen et al., 2006; Whitney et al., 2006). Therefore, diets containing DDGS in this experiment only contained slightly more CP than the control diet, which may have contributed to the positive results of this experiment.

When comparing AA and energy digestibility values for conventional DDGS (Stein et al., 2006; Pedersen et al., 2007) and HP DDG (Widmer et al., 2007), it appears

that HP DDG has a greater energy and AA digestibility. However, ADG, ADFI, and final BW in the grower phase was lower for pigs fed HP DDG compared with pigs fed conventional DDGS. Hastad et al. (2005) reported that decreased feed palatability amplifies with greater concentrations of DDGS in the diet. Therefore, ADFI in the grower phase could have been negatively influenced by the high inclusion level (20 and 40%) of HP DDG. Another possible explanation for the decreased performance is that we may have overestimated the AA digestibility in HP DDG diets. The Lys in the HP DDG could have been heat damaged, and thus, reduced the digestibility in this ingredient. However, overall performance of pigs fed HP DDG was not different from pigs fed the control diet. Therefore, we conclude that HP DDG is a good feed ingredient for pigs but palatability problems may affect pig performance at very high inclusion levels.

Pigs fed corn germ diets had performance that was not different from pigs fed the control or DDGS diets. This observation demonstrates that corn germ is an excellent feed ingredient for pigs and that corn germ can be fed in diets up to at least 10% without negatively influencing pig performance, provided that diets are formulated based on contents of digestible AA.

Carcass Composition

The carcass composition of pigs fed DDGS did not differ between pigs fed the control diets and pigs fed the DDGS containing diets. Whitney et al. (2006) and Cook et al. (2005) reported a decrease in dressing percentage as the inclusion of DDGS increased in the diet, which contrasts with the findings in this experiment. However, the DDGS

used in the previous experiments may have contained more fiber, which may have reduced the dressing percentage.

Pigs fed the HP DDG diets at the highest inclusion levels had a decrease in LM area and LM depth. One possible explanation for this is that pigs fed HP DDG had lower weights at slaughter. Pigs fed HP DDG also had a greater amount of first rib backfat than the pigs fed the control diets, but the fat depth at the other locations was not different from pigs fed the control diets. This observation indicates that HP DDG may influence the location of fat deposition in pigs. We are not aware of other studies that have reported on the location of fat deposition, but more research in this area is warranted. Last lumbar and first rib backfat also increased as corn germ was added to the diet, where as 10^{th} rib backfat tended to decrease. These observations indicate that corn germ also may influence the location of fat deposition in pigs.

Muscle and Fat Quality

The linear decrease in LM b* values for pigs fed diets containing DDGS or HP DDG show that muscle colors became more blue as these ingredients were included in the diets. There are no other reports on LM b* values for pigs fed DDGS or HP DDG, but the increased blueness in LM from pigs fed diets containing DDGS or HP DDG could be a result of the numerical increase in pH that was seen.

Belly firmness and adjusted belly firmness decreased as the concentration of DDGS increased in the diet, which corresponds with Whitney et al. (2006). However, no difference in belly thickness and iodine value was seen in this experiment; this is in contrast to Whitney et al. (2006) who reported a decrease in belly thickness and an

increase in iodine value as the concentration of DDGS increased. However, Whitney et al. (2006) only decreased the inclusion of soybean oil by approximately 0.5% for each 10% increase in DDGS in the diets. Therefore, in the study by Whitney et al. (2006) the dietary concentration of unsaturated fatty acids was greater as the inclusion level of DDGS increased. In the present experiment, 1% soybean oil was removed from the formula for each 10% DDGS included in the diet. Therefore, the concentration of fat in the DDGS containing diets was slightly lower than in the control diet in the present study.

The iodine value of bellies increased as the concentration of HP DDG increased in the diet, which was expected because belly firmness and adjusted belly firmness had a tendency to decrease as the concentration of HP DDG increased. This corresponds with the iodine values of the diets, which increased as the concentration of HP DDG increased. Another possible explanation for the increased iodine value in pigs fed diets containing HP DDG is that these pigs were lighter at slaughter because of decreased feed intake; therefore, less of their fat was produced by de novo synthesis. Consequently, pigs fed HP DDG incorporated more dietary fat into their tissue than pigs fed the control diet. Because the dietary fat was mostly unsaturated, this increased iodine values in the pigs fed these diets.

For pigs fed corn germ diets, the belly iodine value decreased at the 10% inclusion level, but not at the 5% inclusion level. One possible explanation for this is that 2%, 1%, and 0% soybean oil was added to the control, 5% corn germ , and 10% corn germ diets, respectively. Soybean oil was added to the diets to ensure that all diets were formulated to contain the same amount of total fat. Therefore, the total fat in the diets did

not increase when corn germ was included in the diets. However, fat in corn germ does not have a high digestibility (Kil et al., 2007). This results in less fat being absorbed in pigs fed diets containing corn germ than pigs fed control diets or DDGS containing diets even if the concentration of fat in the diet is the same among these treatments. Pigs fed the corn germ diets may, therefore, have absorbed less of the unsaturated dietary fat, which in turn explains the reduction in iodine values for these pigs. The reduction in iodine values for pigs fed corn germ diets indicates that it may be possible to avoid increases in iodine values in pigs fed DDGS if corn germ is also added to the diet.

The reduction in L* and increase in a* and b* values for gilts compared with barrows indicate that gilts have darker, but also more red and yellow colored fat than barrows. It has been reported that an increase in unsaturated fatty acids may increase the redness in pork (Averette Gatlin et al., 2003). In this experiment, fatty acid composition of fat was not determined, but the iodine values for gilts were greater than for barrows, which indicate an increase in the unsaturation of fatty acids (Eggert et al., 2001). This observation is consistent with the fact that gilts deposit greater quantities of C18:2 and C18:3 fatty acids than barrows (Piedrafita et al., 2001).

Palatability

The palatability of pork from pigs fed diets containing DDGS, HP DDG, and corn germ has not been previously reported. Tenderness of bacon seemed to decrease with increasing levels of DDGS in diets, which may be a result of the tendency for reduced distortion of bacon from pigs fed DDGS containing diets.

The interactions between gender and diet for pork chop tenderness, juiciness, and flavor intensity are difficult to explain and need to be verified in future research. Overall, the palatability of bacon and pork chops was not affected by dietary treatment which indicates that consumers would not be able to tell the difference among samples of pork obtained from pigs fed a corn-soybean meal based diet or diets containing DDGS, HP DDG, or corn germ.

IMPLICATION

Including 20% corn distillers dried grains with solubles in diets fed to growing-finishing pigs has no negative effects on growth performance, carcass composition, muscle quality, or pork palatability when diets are formulated based on standardized ileal digestibility of amino acids. Belly firmness is negatively affected if 20% distillers dried grains with solubles are included in the diet, and 20%, therefore, is probably the maximum inclusion in finishing diets. It can be concluded that distillers dried grains with solubles is an appropriate feed ingredient for pigs, but it may decrease fat quality. High-protein distillers dried grains do not affect final pig performance, but belly firmness and iodine values are negatively influenced by the addition of high-protein distillers dried grains in the diet. Therefore, it can be concluded that high protein distillers dried grains can be fed to pigs, but fat quality may be reduced. Including 10% corn germ in diets has no detrimental effects on growth performance, carcass quality, or pork palatability if diets are formulated based on digestible amino acid concentrations. It can be concluded that

corn germ is an excellent feed source for grow-finish pigs and can be included in diets up to at least 10%.

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Table 4.1. Analyzed nutrient composition of ingredients (as-fed basis)

Item Ingredients:	Corn	Soybean meal	DDGS[1]	HP DDG[2]	Corn germ
DM, %	85.20	87.80	91.40	87.50	90.60
CP, %	6.93	43.95	27.46	42.51	15.56
Crude fat, %	2.24	1.25	9.49	3.01	17.32
Ca, %	0.02	0.48	0.28	0.02	0.01
P, %	0.22	0.66	0.74	0.38	1.31
Iodine value	109.50	107.20	123.90	110.90	120.70
Indispensable AA, %					
Arginine	0.32	2.99	1.16	1.50	1.11
Histidine	0.19	1.11	0.73	1.06	0.43
Isoleucine	0.24	1.90	0.99	1.70	0.44
Leucine	0.85	3.27	3.06	6.03	1.11
Lysine	0.22	2.76	0.88	1.11	0.78
Methionine	0.18	0.61	0.58	0.89	0.27
Phenylalanine	0.34	2.12	1.31	2.46	0.59
Threonine	0.25	1.67	1.04	1.56	0.53
Tryptophan	0.05	0.57	0.22	0.27	0.10
Valine	0.33	2.06	1.37	2.11	0.74
Dispensable AA, %					
Alanine	0.52	1.87	1.83	3.24	0.91
Aspartic acid	0.47	4.79	1.71	2.67	1.14

Cysteine	0.16	0.68	0.61	0.81	0.33
Glutamic acid	1.26	7.58	4.01	7.27	2.05
Glycine	0.27	1.82	1.03	1.32	0.77
Proline	0.60	2.08	2.10	3.58	0.97
Serine	0.33	1.91	1.18	1.95	0.61
Tyrosine	0.22	1.60	1.11	2.02	0.43

[1]DDGS = distillers dried grains with solubles.

[2]HP DDG = high-protein distillers dried grains.

Table 4.2. Analyzed fatty acid composition of ingredients (% of total fat)

Item Ingredients:	Corn	Soybean meal	DDGS[1]	HP DDG[2]	Corn germ
Caprylic acid 8:0	0.00	0.12	0.16	0.00	0.00
Myristic acid 14:0	0.00	0.18	0.00	0.00	0.00
Palmitic acid 16:0	12.80	14.00	13.40	14.40	11.00
Palmitoleic acid 16:1	0.14	0.19	0.12	0.19	0.11
Heptadecanoic acid 17:0	0.00	0.17	0.00	0.00	0.10
Stearic acid 18:0	2.01	4.62	2.37	2.72	1.90
Oleic acid 18:1	28.60	16.80	27.00	24.80	26.80
Linoleic acid 18:2	52.80	50.40	52.80	52.40	57.20
Linolenic acid 18:3	1.30	9.34	1.38	1.66	1.10
Arachidic acid 20:0	0.46	0.31	0.45	0.43	0.41
ll-eicosenoic acid 20:1	0.36	0.19	0.27	0.29	0.28
Eicosadienoic acid 20:2	0.00	0.00	0.18	0.00	0.00
Eicosadienoic acid 20:3	0.00	0.00	0.12	0.31	0.00
Arachidonic 20:4	0.00	0.13	0.00	0.00	0.00
Behenic acid 22:0	0.18	0.48	0.19	0.19	0.15
Lignoceric acid 24:0	0.24	0.32	0.27	0.26	0.19
Saturated fat, total	15.60	20.10	16.80	17.80	13.60

[1]DDGS = distillers dried grains with solubles.

[2]HP DDG = high-protein distillers dried grains.

Table 4.3. Ingredient composition of grower diets (as-fed basis)

Diet:	Control	DDGS[1]		HP DDG[2]		Corn germ	
Ingredient, %		10%	20%	Low	High	5%	10%
Corn	67.15	62.78	58.41	61.03	54.90	66.07	64.96
Soybean meal	28.50	23.90	19.30	14.25	-	25.50	22.50
DDGS[1]	-	10.00	20.00	-	-	-	-
Corn germ	-	-	-	-	-	5.00	10.00
HP DDG[2]	-	-	-	20.00	40.00	-	-
Soybean oil	2.00	1.00	-	2.00	2.00	1.00	-
Limestone	0.90	0.99	1.07	1.06	1.21	0.93	0.96
MCP[3]	0.87	0.65	0.44	0.79	0.71	0.85	0.84
L-lysine HCL	-	0.10	0.20	0.27	0.54	0.07	0.14
L-threonine	-	-	-	-	-	-	0.02
L-tryptophan	-	-	-	0.02	0.06	-	-
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin premix[4]	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Micromineral premix[4]	0.15	0.15	0.15	0.15	0.15	0.15	0.15

[1]DDGS = distillers dried grains with solubles.

[2]HP DDG = high-protein distillers dried grains.

[3]MCP = monocalcium phosphate.

[4]The vitamin premix provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 6,594 IU as acetate; vitamin $D_{3,}$ 989 IU as D-activated animal sterol; vitamin E, 33 IU as alpha tocopherol acetate; vitamin K_3, 2.6 mg as menadione dimethylpyrimidinol bisulphite; thiamin, 2.0 mg as thiamine mononitrate; riboflavin, 5.9 mg; pyridoxine, 2.0 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.026 mg; D-pantothenic acid, 20 mg as calcium pantothenate; niacin, 33 mg; folic acid, 0.66 mg; biotin, 0.1 mg.

[5]The micromineral premix provided the following quantities of micro minerals per kilogram of complete diet: Se, 0.18 mg as sodium selenite; I, 0.22 mg as potassium iodate; Cu, 9.5 mg as copper sulfate; Mn, 26.5 mg as manganese sulfate; Fe, 99 mg as iron sulfate; Zn, 99 mg as zinc oxide.

Table 4.4. Ingredient composition of early finisher diets (as-fed basis)

Diet:	Control	DDGS[1]		HP DDG[2]		Corn germ	
Ingredient, %		10%	20%	Low	High	5%	10%
Corn	74.36	69.79	65.22	69.88	65.37	73.07	71.78
Soybean meal	21.60	17.20	12.80	10.80	-	18.80	16.00
DDGS[1]	-	10.00	20.00	-	-	-	-
Corn germ	-	-	-	-	-	5.00	10.00
HP DDG[2]	-	-	-	15.00	30.00	-	-
Soybean oil	2.00	1.00	-	2.00	2.00	1.00	-
Limestone	0.77	0.85	0.94	0.88	1.00	0.80	0.82
Monocalcium phosphate	0.69	0.48	0.27	0.64	0.59	0.68	0.67
L-lysine HCL	-	0.10	0.19	0.21	0.41	0.07	0.13
L-threonine	-	-	-	-	-	-	0.02
L-tryptophan	-	-	-	0.01	0.05	-	-
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin premix[3]	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Micromineral premix[4]	0.15	0.15	0.15	0.15	0.15	0.15	0.15

[1]DDGS = distillers dried grains with solubles.

[2]HP DDG = high-protein distillers dried grains.

[3]The vitamin premix provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 6,594 IU as acetate; vitamin D_3, 989 IU as D-activated

animal sterol; vitamin E, 33 IU as alpha tocopherol acetate; vitamin K_3, 2.6 mg as menadione dimethylpyrimidinol bisulphite; thiamin, 2.0 mg as thiamine mononitrate; riboflavin, 5.9 mg; pyridoxine, 2.0 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.026 mg; D-pantothenic acid, 20 mg as calcium pantothenate; niacin, 33 mg; folic acid, 0.66 mg; biotin, 0.1 mg.

[4]The micromineral premix provided the following quantities of micro minerals per kilogram of complete diet: Se, 0.18 mg as sodium selenite; I, 0.22 mg as potassium iodate; Cu, 9.5 mg as copper sulfate; Mn, 26.5 mg as manganese sulfate; Fe, 99 mg as iron sulfate; Zn, 99 mg as zinc oxide.

Table 4.5. Ingredient composition of late finisher diets (as-fed basis)

Diet:	Control	DDGS[1]		HP DDG[2]		Corn germ	
Ingredient, %		10%	20%	Low	High	5%	10%
Corn	81.03	76.66	72.27	78.37	75.71	79.75	78.45
Soybean meal	15.10	10.5	5.90	7.55	-	12.30	9.50
DDGS[1]	-	10.00	20.00	-	-	-	-
Corn germ	-	-	-	-	-	5.00	10.00
HP DDG[2]	-	-	-	10.00	20.00	-	-
Soybean oil	2.00	1.00	-	2.00	2.00	1.00	-
Limestone	0.77	0.85	0.93	0.84	0.92	0.79	0.82
Monocalcium phosphate	0.52	0.31	0.10	0.49	0.45	0.51	0.50
L-lysine HCL	-	0.10	0.20	0.15	0.30	0.07	0.13
L-threonine	-	-	-	-	-	-	0.01
L-tryptophan	-	-	0.02	0.02	0.04	-	0.01
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin premix[3]	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Micromineral premix[4]	0.15	0.15	0.15	0.15	0.15	0.15	0.15

[1]DDGS = distillers dried grains with solubles.

[2]HP DDG = high-protein distillers dried grains.

[3]The vitamin premix provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 6,594 IU as acetate; vitamin D_3, 989 IU as D-activated

animal sterol; vitamin E, 33 IU as alpha tocopherol acetate; vitamin K_3, 2.6 mg as menadione dimethylpyrimidinol bisulphite; thiamin, 2.0 mg as thiamine mononitrate; riboflavin, 5.9 mg; pyridoxine, 2.0 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.026 mg; D-pantothenic acid, 20 mg as calcium pantothenate; niacin, 33 mg; folic acid, 0.66 mg; biotin, 0.1 mg.

[4]The micromineral premix provided the following quantities of micro minerals per kilogram of complete diet: Se, 0.18 mg as sodium selenite; I, 0.22 mg as potassium iodate; Cu, 9.5 mg as copper sulfate; Mn, 26.5 mg as manganese sulfate; Fe, 99 mg as iron sulfate; Zn, 99 mg as zinc oxide.

Table 4.6. Analyzed nutrient composition of grower diets (as-fed basis)

Diet:	Control	DDGS[1]		HP DDG[2]		Corn germ	
Item		10%	20%	Low	High	5%	10%
DM, %	88.40	88.80	88.50	88.80	89.80	88.30	88.40
CP, %	17.19	17.70	17.90	18.85	21.30	16.34	15.34
Crude Fat, %	4.55	4.35	3.84	4.73	4.71	4.26	4.31
Ca, %	0.61	0.65	0.63	0.60	0.64	0.65	0.61
P, %	0.51	0.52	0.50	0.46	0.43	0.54	0.58
Iodine value	116.30	113.70	115.80	117.20	118.50	116.90	115.40
Indispensable AA, %							
Arginine	1.09	1.03	0.96	0.90	0.78	1.06	0.94
Histidine	0.46	0.47	0.47	0.47	0.53	0.45	0.40
Isoleucine	0.75	0.73	0.70	0.69	0.83	0.71	0.60
Leucine	1.52	1.64	1.71	2.14	2.86	1.48	1.33
Lysine	0.97	0.96	0.98	0.90	1.03	1.01	0.89
Methionine	0.27	0.29	0.29	0.36	0.41	0.27	0.24
Phenylalanine	0.85	0.90	0.84	0.99	1.16	0.83	0.72
Threonine	0.64	0.65	0.65	0.70	0.74	0.62	0.56
Tryptophan	0.18	0.18	0.16	0.17	0.17	0.16	0.16
Valine	0.80	0.80	0.88	0.81	1.04	0.85	0.75
Dispensable AA, %							
Alanine	0.88	0.96	1.02	1.21	1.59	0.87	0.80

Aspartic acid	1.71	1.63	1.51	1.50	1.30	1.64	1.39
Cysteine	0.31	0.33	0.33	0.38	0.40	0.31	0.28
Glutamic acid	3.01	2.95	2.92	3.31	3.75	2.92	2.56
Glycine	0.72	0.71	0.71	0.67	0.68	0.71	0.64
Proline	0.97	1.08	1.15	1.36	1.76	0.97	0.90
Serine	0.73	0.72	0.72	0.84	0.90	0.71	0.63
Tyrosine	0.59	0.64	0.62	0.74	0.88	0.58	0.52

[1]DDGS = distillers dried grains with solubles.

[2]HP DDG = high-protein distillers dried grains.

Table 4.7. Analyzed nutrient composition of early finisher diets (as-fed basis)

Diet:	Control	DDGS[1]		HP DDG[2]		Corn germ	
Item		10%	20%	Low	High	5%	10%
DM, %	86.60	87.00	87.00	87.60	88.30	87.60	87.60
CP, %	14.78	15.03	16.44	16.10	18.76	13.74	13.80
Crude fat, %	4.00	3.72	3.85	4.56	4.99	4.27	4.23
Ca, %	0.49	0.48	0.55	0.50	0.44	0.51	0.51
P, %	0.42	0.44	0.43	0.42	0.37	0.47	0.53
Iodine value	114.40	117.00	117.60	119.00	118.10	117.40	119.00
Indispensable AA, %							
Arginine	0.86	0.89	0.83	0.82	0.68	0.79	0.84
Histidine	0.38	0.41	0.42	0.42	0.45	0.35	0.36
Isoleucine	0.56	0.62	0.61	0.63	0.68	0.52	0.48
Leucine	1.30	1.48	1.63	1.86	2.40	1.27	1.24
Lysine	0.73	0.98	0.83	0.77	0.84	0.72	0.79
Methionine	0.24	0.26	0.30	0.30	0.37	0.23	0.25
Phenylalanine	0.70	0.77	0.79	0.82	0.97	0.65	0.64
Threonine	0.54	0.57	0.59	0.61	0.65	0.50	0.55
Tryptophan	0.15	0.14	0.14	0.14	0.16	0.15	0.13
Valine	0.71	0.79	0.79	0.81	0.87	0.67	0.65
Dispensable AA, %							
Alanine	0.77	0.88	0.97	1.08	1.35	0.75	0.76

Aspartic acid	1.36	1.33	1.29	1.30	1.17	1.20	1.26
Cysteine	0.26	0.28	0.31	0.32	0.36	0.27	0.29
Glutamic acid	2.42	2.67	2.71	2.94	3.28	2.36	2.32
Glycine	0.59	0.64	0.64	0.61	0.60	0.55	0.56
Proline	0.85	0.97	1.08	1.19	1.50	0.84	0.85
Serine	0.63	0.66	0.67	0.72	0.81	0.59	0.62
Tyrosine	0.52	0.57	0.60	0.63	0.74	0.48	0.49

[1]DDGS = distillers dried grains with solubles.

[2]HP DDG = high-protein distillers dried grains.

Table 4.8. Analyzed nutrient composition of late finisher diets (as-fed basis)

Diet:	Control	DDGS[1]		HP DDG[2]		Corn germ	
Item		10%	20%	Low	High	5%	10%
DM, %	87.90	87.40	87.70	87.60	86.80	87.20	87.10
CP, %	11.66	12.07	12.59	13.16	13.64	11.89	11.24
Crude fat, %	4.11	3.75	3.57	3.81	4.01	3.64	3.61
Ca, %	0.57	0.51	0.49	0.47	0.52	0.53	0.56
P, %	0.41	0.39	0.38	0.38	0.37	0.45	0.49
Iodine value	116.60	119.00	116.50	119.00	120.20	119.00	116.60
Indispensable AA, %							
Arginine	0.71	0.65	0.66	0.64	0.53	0.66	0.63
Histidine	0.32	0.33	0.35	0.33	0.33	0.31	0.29
Isoleucine	0.48	0.47	0.47	0.46	0.46	0.44	0.41
Leucine	1.13	1.27	1.37	1.42	1.75	1.13	1.06
Lysine	0.61	0.57	0.70	0.63	0.60	0.58	0.62
Methionine	0.20	0.21	0.26	0.24	0.27	0.19	0.19
Phenylalanine	0.58	0.59	0.60	0.63	0.68	0.54	0.51
Threonine	0.44	0.45	0.49	0.48	0.49	0.43	0.41
Tryptophan	0.13	0.12	0.14	0.13	0.13	0.11	0.13
Valine	0.56	0.57	0.63	0.54	0.57	0.54	0.51
Dispensable AA, %							
Alanine	0.67	0.77	0.85	0.84	1.03	0.69	0.66

Aspartic acid	1.10	1.00	0.99	1.01	0.88	1.00	0.91
Cysteine	0.23	0.25	0.30	0.29	0.29	0.25	0.23
Glutamic acid	2.10	2.15	2.21	2.29	2.47	1.98	1.85
Glycine	0.48	0.49	0.52	0.48	0.46	0.47	0.45
Proline	0.76	0.87	0.95	0.92	1.13	0.76	0.74
Serine	0.55	0.56	0.61	0.63	0.67	0.53	0.49
Tyrosine	0.39	0.42	0.45	0.46	0.52	0.39	0.36

[1]DDGS = distillers dried grains with solubles.

[2]HP DDG = high-protein distillers dried grains.

Table 4.9. Growth performance of growing-finishing pigs fed experimental diets[1]

Item	Diet:	Control	DDGS[2]		HP DDG[3]		Corn germ		DDGS[2]			HP DDG[3]			Corn germ[4]		
									SEM	*P* – value		SEM	*P* – value		SEM	*P* – value	
			10%	20%	Low	High	5%	10%		L[5]	Q[5]		L[5]	Q[5]		L[5]	Q[5]
Grower period																	
Initial weight, kg		22.10	21.85	22.03	22.47	22.65	22.12	22.18	0.483	0.821	0.403	0.513	0.416	0.874	0.416	0.813	0.935
ADG, kg[6]		0.81	0.87	0.83	0.76	0.68	0.84	0.83	0.035	0.653	0.205	0.048	0.005	0.580	0.030	0.381	0.471
ADFI, kg[6]		1.78	1.92	1.89	1.71	1.58	1.87	1.90	0.066	0.180	0.217	0.097	0.028	0.706	0.082	0.136	0.647
G:F, kg/kg		0.45	0.46	0.44	0.44	0.43	0.45	0.44	0.012	0.363	0.496	0.008	0.097	0.873	0.007	0.055	0.508
Final weight, kg[6]		59.2	62.0	60.1	57.5	54.1	60.6	60.5	1.76	0.704	0.291	2.35	0.017	0.576	1.58	0.379	0.520
Early finisher period																	
ADG, kg		0.99	1.03	0.97	0.98	0.93	1.01	1.06	0.030	0.622	0.063	0.035	0.255	0.610	0.025	0.045	0.563
ADFI, kg[6]		2.99	3.15	3.04	2.94	2.76	3.05	3.16	0.092	0.734	0.243	0.105	0.127	0.587	0.147	0.425	0.859
G:F, kg/kg[6]		0.33	0.33	0.32	0.35	0.34	0.33	0.34	0.007	0.354	0.743	0.007	0.526	0.052	0.016	0.579	0.774
Final weight, kg[6]		98.6	103.4	98.9	96.7	91.3	100.8	102.7	1.90	0.903	0.064	2.95	0.067	0.583	1.62	0.083	0.922
Late finisher period																	
ADG, kg		0.91	0.87	0.93	0.90	0.94	0.90	1.00	0.064	0.778	0.411	0.047	0.535	0.624	0.066	0.240	0.394
ADFI, kg		3.26	3.52	3.14	3.39	3.08	3.30	3.66	0.181	0.648	0.167	0.144	0.375	0.237	0.157	0.094	0.428
G:F, kg/kg		0.28	0.24	0.30	0.27	0.31	0.27	0.27	0.016	0.308	0.012	0.012	0.100	0.058	0.018	0.726	0.596
Final weight, kg		124.1	127.7	124.9	122.0	117.7	126.0	130.6	2.77	0.772	0.228	3.18	0.174	0.777	2.40	0.046	0.651
Entire growing-finishing period																	
Initial weight, kg		22.10	21.85	22.03	22.47	22.65	22.12	22.18	0.483	0.821	0.403	0.513	0.416	0.874	0.416	0.813	0.935

ADG, kg[6]	0.89	0.93	0.90	0.87	0.83	0.91	0.95	0.023	0.758	0.224	0.025	0.111	0.781	0.019	0.055	0.633
ADFI, kg[6]	2.57	2.75	2.60	2.55	2.36	2.63	2.77	0.078	0.783	0.110	0.078	0.079	0.371	0.093	0.138	0.746
G:F, kg/kg	0.35	0.34	0.35	0.34	0.35	0.35	0.35	0.008	0.944	0.323	0.009	0.755	0.441	0.010	0.743	0.928
Final weight, kg	124.1	127.7	124.9	122.0	117.7	126.0	130.6	2.77	0.772	0.228	3.18	0.174	0.777	2.40	0.046	0.651

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

[2]DDGS = distillers dried grains with solubles.

[3]HP DDG = high-protein distillers dried grains.

[4]No differences between corn germ and DDGS were observed.

[5]L = Linear effect, Q = Quadratic effect.

[6]DDGS different from HP DDG ($P < 0.05$).

Table 4.10. Effects of dietary treatments on carcass composition[1]

Item	Diet:	Control	DDGS[2]		HP DDG[3]		Corn germ		DDGS[2]			HP DDG[3, 4]			Corn germ		
									SEM	*P*- value		SEM	*P*- value		SEM	*P*- value	
			10%	20%	Low	High	5%	10%		L[5]	Q[5]		L[5]	Q[5]		L[5]	Q[5]
Live wt., kg		124.0	127.7	124.9	122.0	118.0	126.0	130.6	3.20	0.830	0.360	3.67	0.250	0.830	3.33	0.175	0.742
HCW, kg		88.3	91.7	88.7	86.6	82.5	89.6	93.8	2.52	0.907	0.241	2.95	0.180	0.752	2.59	0.145	0.646
Dressing, %		71.1	71.7	71.0	70.8	69.8	71.1	71.8	0.47	0.843	0.225	0.65	0.143	0.629	0.48	0.309	0.530
Lean meat,[6] %		51.3	50.2	51.2	52.9	51.3	53.6	51.8	1.20	0.916	0.320	1.10	0.978	0.111	1.14	0.603	0.009
LM area,[6] cm^2		46.6	45.0	44.7	46.8	40.6	49.0	50.1	2.48	0.511	0.792	1.49	0.008	0.080	2.47	0.179	0.771
LM depth, cm		6.06	5.93	5.76	6.01	5.40	5.95	6.26	0.242	0.250	0.937	0.178	0.022	0.208	0.246	0.449	0.339
10th rib backfat, cm		2.50	2.60	2.40	2.23	2.34	2.11	2.48	0.204	0.687	0.441	0.196	0.522	0.335	0.174	0.932	0.052
Last lumbar, backfat, cm		2.11	2.30	2.26	2.18	2.29	1.97	2.59	0.164	0.539	0.560	0.243	0.552	0.924	0.194	0.043	0.059
Last rib, backfat, cm		2.29	2.72	2.51	2.44	2.51	2.57	2.62	0.139	0.272	0.076	0.173	0.369	0.810	0.160	0.157	0.554
First rib, backfat, cm		4.54	4.87	4.84	4.67	5.45	4.65	5.11	0.181	0.250	0.419	0.260	0.035	0.323	0.155	0.017	0.370

[1]Data are means of 12 observations per treatment; except last lumbar, last rib, and first rib backfat which has 8 observations per treatment.

[2]DDGS = distillers dried grains with solubles.

[3]HP DDG = high-protein distillers dried grains.

[4]No differences between HP DDG and DDGS were observed.

[5]L = Linear effect, Q = Quadratic effect.

[6]DDGS different from corn germ ($P < 0.05$).

Table 4.11. Effects of dietary treatments on muscle and fat quality[1]

Item	Diet:	Control	DDGS[2]		HP DDG[3]		Corn germ		DDGS[2]			HP DDG[3, 4]			Corn germ		
									SEM	*P*- value		SEM	*P*- value		SEM	*P*- value	
			10%	20%	Low	High	5%	10%		L[5]	Q[5]		L[5]	Q[5]		L[5]	Q[5]
Muscle Quality																	
Marbling[6]		2.17	2.13	2.29	2.21	2.26	2.33	2.25	0.403	0.681	0.693	0.444	0.549	0.991	0.368	0.716	0.530
LM color score[6]		3.38	3.17	3.25	3.13	2.97	3.38	3.17	0.243	0.651	0.544	0.236	0.231	0.863	0.224	0.479	0.680
LM color, L*		59.5	58.7	58.2	60.1	59.8	58.4	58.6	0.92	0.334	0.913	0.89	0.837	0.661	1.21	0.599	0.675
LM color, a*		8.22	7.95	7.97	7.88	7.51	7.73	8.16	0.495	0.648	0.766	0.534	0.209	0.977	0.457	0.916	0.331
LM color, b*		16.69	16.17	15.55	15.95	15.67	15.28	16.20	0.376	0.034	0.904	0.326	0.037	0.567	0.446	0.449	0.050
24-h pH, LM		5.35	5.37	5.43	5.39	5.39	5.41	5.41	0.055	0.093	0.651	0.042	0.260	0.537	0.047	0.194	0.417
48-h drip loss, %		4.04	4.28	3.89	4.34	4.17	2.91	4.42	0.493	0.840	0.603	0.640	0.859	0.726	0.445	0.550	0.025
7-d purge loss, %		3.22	3.29	3.23	3.87	3.02	2.96	3.14	0.439	0.985	0.880	0.483	0.685	0.090	0.410	0.885	0.659
Fat Quality																	
Fat color,[7] L*		81.6	82.0	80.1	81.4	80.7	81.6	81.9	0.64	0.058	0.069	0.59	0.291	0.713	0.65	0.656	0.829
Fat color,[7] a*		1.71	1.82	1.78	1.47	1.58	1.38	1.52	0.284	0.860	0.819	0.359	0.692	0.558	0.337	0.635	0.498
Fat color,[7] b*		10.43	10.48	11.11	10.73	11.10	10.17	10.69	0.289	0.106	0.417	0.355	0.205	0.942	0.347	0.552	0.307
Belly thickness, cm		4.33	4.66	4.13	4.09	4.17	4.09	4.64	0.248	0.572	0.179	0.204	0.593	0.510	0.201	0.289	0.117
Belly firmness score,[8] degrees		54.0	55.0	40.1	44.9	43.3	49.6	62.1	4.27	0.016	0.080	4.52	0.054	0.412	6.62	0.282	0.201
Adjusted belly firmness score,[9] degrees		53.70	54.0	41.3	45.7	43.4	51.3	60.2	4.43	0.010	0.126	4.36	0.057	0.565	7.38	0.381	0.341
Belly temperature, °C		4.77	4.77	4.72	5.00	4.43	4.90	4.85	0.456	0.814	0.892	0.509	0.103	0.027	0.480	0.643	0.579
Iodine value[10]		69.8	69.8	72.0	72.0	75.3	69.9	64.7	1.25	0.219	0.489	1.01	0.004	0.656	9.31	0.001	0.025

[1]Data are means of 12 observations per treatment.

[2]DDGS = distillers dried grains with solubles.

[3]HP DDG = high-protein distillers dried grains.

[4]No differences between HP DDG and DDGS were observed.

[5]L = Linear effect, Q = Quadratic effect.

[6]National Pork Producers Council (NPPC, 1999).

[7]Fat color scores were obtained just cranial to the 10^{th} rib in the second layer of fat, counting from the skin inward.

[8]Belly firmness score = cos – 1 {[0.5(L2) – D2]/[0.5(L2]}, where L = belly length measured on a flat surface and D = the distance between the 2 ends of a suspended belly; greater belly firmness scores indicate firmer bellies.

[9]Belly firmness score adjusted for belly thickness.

[10]DDGS different from corn germ ($P < 0.05$).

Table 4.12. Effects of gender on fat quality[1]

Item	Gender			
	Barrow	Gilt	SEM	*P*-value
Fat color,[2] L*	82.2	80.4	0.43	< 0.001
Fat color,[2] a*	1.3	2.0	0.21	< 0.001
Fat color,[2] b*	10.2	11.2	0.16	< 0.001
Belly thickness, cm	5.0	3.6	0.11	< 0.001
Belly firmness score,[3] degrees	60.0	40.6	4.75	< 0.001
Adjusted belly firmness score,[4] degrees	55	45	5.2	0.100
Belly temperature, C°	4.8	4.7	0.46	0.184
Iodine value	67.8	73.2	0.74	< 0.001

[1]Data are means of 42 gilts and 41 barrows per observation.

[2]Fat color scores were obtained just cranial to the 10th rib in the second layer of fat, counting from the skin inward.

[3]Belly firmness score = cos-1{[0.5(L2) – D2]/[0.5(L2)]}, where L = belly length measured on a flat surface and D = the distance between the 2 ends of a suspended belly; greater belly firmness scores indicate firmer bellies.

[4]Belly firmness score adjusted for belly thickness.

Table 4.13. Effects of dietary treatments on the palatability of bacon and pork chops[1]

Item	Diet:	Control	DDGS[2]		HP DDG[3]		Corn germ		DDGS[2]			HP DDG[3]			Corn germ		
									SEM	*P* - value		SEM	*P* - value		SEM	*P* - value	
			10%	20%	Low	High	5%	10%		L[4]	Q[4]		L[4]	Q[4]		L[4]	Q[4]
Cook loss, %		28.6	28.5	26.5	28.9	27.2	27.4	28.0	1.14	0.089	0.333	1.04	0.224	0.273	1.30	0.610	0.381
Shear force, kg		3.55	3.60	3.59	3.46	3.16	3.64	3.64	0.229	0.899	0.904	0.190	0.159	0.671	0.164	0.716	0.824
Bacon distortion[5]		2.42	2.14	1.96	2.17	2.12	2.66	2.38	0.175	0.072	0.833	0.262	0.324	0.688	0.217	0.891	0.224
Bacon palatability																	
Crispiness[6]		4.16	3.86	4.64	4.18	4.17	4.35	3.91	0.223	0.124	0.066	0.205	0.887	0.964	0.231	0.385	0.150
Tenderness[6]		5.34	5.55	4.79	5.11	5.18	4.86	5.15	0.191	0.046	0.049	0.185	0.532	0.497	0.207	0.414	0.056
Bacon flavor intensity[6]		5.55	5.72	5.54	5.21	5.83	5.56	5.56	0.192	0.966	0.452	0.234	0.352	0.069	0.213	1.000	1.000
Fattiness taste[7]		2.37	2.40	2.09	2.02	2.26	2.20	2.36	0.114	0.063	0.209	0.134	0.585	0.076	0.128	0.954	0.275
Rancid taste[7]		1.16	1.10	1.06	1.20	1.16	1.10	1.04	0.044	0.071	0.908	0.061	0.988	0.501	0.044	0.076	0.938
Piggy taste[7]		1.08	1.14	1.05	1.20	1.17	1.11	1.16	0.040	0.530	0.124	0.063	0.329	0.382	0.059	0.330	0.809
Fishy taste[7]		1.02	1.00	1.00	1.00	1.00	1.00	1.00	0.009	0.137	0.294	0.009	0.111	0.337	0.009	0.098	0.354
Pork chop palatability																	
Tenderness[6, 8]																	
Barrow		5.32	4.59	6.00	5.09	6.39	5.27	5.58	0.323	0.349	0.016	0.274	0.077	0.138	0.286	0.534	0.654
Gilt		5.94	5.27	5.02	5.88	5.67	5.46	5.54	0.320	0.017	0.510	0.271	0.120	0.729	0.286	0.246	0.351
Juiciness[6, 9]																	
Barrow		3.99	4.22	4.98	4.35	5.24	4.82	4.64	0.249	0.049	0.338	0.286	0.019	0.457	0.296	0.177	0.379
Gilt		4.78	4.57	3.92	4.52	4.47	4.54	4.46	0.244	0.021	0.135	0.288	0.643	0.793	0.305	0.287	0.204

Pork flavor intensity[6, 10]																
Barrow	5.02	5.00	5.55	5.12	5.71	5.00	5.23	0.196	0.177	0.185	0.224	0.092	0.410	0.158	0.472	0.662
Gilt	4.81	5.18	4.91	5.34	4.69	5.00	5.03	0.194	0.545	0.045	0.218	0.788	0.011	0.162	0.081	0.850
Off flavor intensity[11]	1.32	1.33	1.19	1.24	1.29	1.39	1.36	0.084	0.088	0.314	0.074	0.784	0.451	0.084	0.547	0.498
Metallic taste[12]	0.34	0.58	0.00	0.25	0.00	0.33	0.33	0.171	0.055	0.017	0.134	0.086	0.607	0.167	1.000	1.000
Piggy taste[12]	0.58	0.67	0.42	0.77	0.88	0.73	0.88	0.213	0.584	0.528	0.265	0.326	0.873	0.243	0.321	0.956
Other off flavors[12]	1.14	0.56	0.67	0.52	0.88	1.09	1.00	0.380	0.180	0.276	0.396	0.524	0.235	0.373	0.836	0.850
Total off flavors[12]	2.08	1.72	1.08	1.56	1.73	2.16	2.18	0.469	0.072	0.783	0.532	0.599	0.570	0.529	0.868	0.944

[1]Data are means of 12 observations per treatment.

[2]DDGS = distillers dried grains with solubles.

[3]HP DDG = high-protein distillers dried grains.

[4]L = Linear effect, Q = Quadratic effect.

[5]Distortion Score: 5 = extremely distorted, 1 = no distortion.

[6]Crispiness, tenderness, flavor intensity, and juiciness score: 8 = extremely crispy, extremely tender, extremely intense flavor, or extremely juicy, 1 = extremely soft, extremely tough, extremely bland, or extremely dry.

[7]Fattiness, rancid flavor, piggy flavor, or fishy flavor score: 5 = extremely fatty, extremely rancid, extremely piggy, or extremely fishy, 1 = not fatty, not rancid, not piggy, or not fishy.

[8]Diet × gender interaction ($P < 0.05$) for DDGS.

[9]Diet × gender interaction ($P < 0.05$) for DDGS, HP DDG, and corn germ.

[10]Diet × gender interaction ($P < 0.05$) for HP DDG.

[11]Off flavor intensity score: 4 = extreme off flavor; 1 = no off flavor

[12]Number of yes responses regarding off-flavor per 8 panel member.

CHAPTER 5

OVERALL CONCLUSION

From the first 3 experiments that are reported in this thesis, it is concluded that high-protein distillers dried grains (**HP DDG**) has a greater digestibility of energy, P, and most AA than corn germ. In addition, HP DDG has a greater digestibility of energy and most AA than previously reported for conventional distillers dried grains with solubles (**DDGS**) and corn. The digestibility of P in HP DDG is similar to values previously reported for conventional DDGS, but greater than in corn. Corn germ has lower energy and AA digestibility values than previously reported for corn and conventional DDGS. However, the DE and ME in corn germ is similar to corn.

In the last experiment reported in this thesis, it is concluded that including 20% DDGS in grow-finish pig diets has no negative effects on growth performance, carcass composition, muscle quality, or pork palatability when diets are formulated based on standardized ileal digestibility (**SID**) of AA. Belly firmness is negatively affected if 20% DDGS are included in the diet, and 20%, therefore, is probably the maximum inclusion in finishing diets. It is concluded that DDGS is an appropriate feed ingredient for pigs, but it may decrease fat quality. High-protein distillers dried grains do not affect final pig performance, but belly firmness and iodine values are negatively influenced by the addition of HP DDG in the diet. Therefore, it is concluded that HP DDG can be fed to pigs without reducing pig performance, but pigs fed HP DDG may have reduced belly fat quality. Including 10% corn germ in diets fed to growing-finishing pigs has no detrimental effects on growth performance, carcass quality, or pork palatability if diets

are formulated based on digestible AA concentrations. It is concluded that corn germ is an excellent feed source for grow-finish pigs and can be included in diets up to at least 10%.