14 Feeding Ethanol Coproducts to Swine

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CONTENTS

14.1 INTRODUCTION

Utilization of ethanol coproducts to reduce diet costs has become important as more U.S.-grown corn is used in the fuel ethanol industry. While the majority of the distillers dried grains with solubles (DDGS) that is produced is used in diets fed to ruminants such as beef cattle (Chapter 12) and dairy cows (Chapter 13), DDGS has also been used in the feeding of swine for more than 50 years. However, new production technologies and new corn varieties have changed the gross composition of the grain, which now contains less protein and more fat than in the past. Please refer to Chapters 5 and 8 for details on ethanol production and DDGS composition. The changes in the composition of corn that have been observed during the past decades influence DDGS composition and may also change the response of pigs to diets containing DDGS. New production technologies in ethanol plants such as front-end fractionation or back-end separation have resulted in the production of a number of novel coproducts from the ethanol industry. Research to measure the nutritional value of these products has been conducted in recent years. Considerable new information about feeding ethanol coproducts to swine has, therefore, been generated during the last decade and currently much of this information is being implemented in the swine industry. The objective of this chapter is to summarize current knowledge about feeding ethanol coproducts to swine.

14.2 ETHANOL COPRODUCTS USED IN DIETS FED TO SWINE

Corn and sorghum are two grains that are most often used in the production of ethanol in the United States, with corn being predominant. Blends of sorghum and corn are sometimes also used (Urriola et al., 2009). In Europe and Canada, however, wheat and sometimes barley may be used in ethanol production. The composition of the DDGS obtained from ethanol production depends on the grain that was used and there are, therefore, differences among sources of DDGS depending on grain type. DDGS may also be produced as a result of beverage distillation, but the nutritional quality of DDGS originating from beverage distillation is not different from the quality of DDGS produced from ethanol distillation (Pahm et al., 2008a). Other factors that have been suggested to influence the composition and nutritional value of DDGS include the region in which the grain is produced (Fastinger and Mahan, 2006), but it has been demonstrated that in the United States, the variation in nutritional value of DDGS among regions is no greater than within regions (Pahm et al., 2008a; Stein et al., 2009).

While DDGS is the most common and best known coproduct from the ethanol industry, other coproducts are also produced. If the solubles are not added back to the fermented grain, a product called distillers dried grains (DDG) is produced. This product may have a greater nutritional value than DDGS, because addition of solubles to the fermented grain may increase the heat damage of the amino acids (AA) in the product (Pahm et al., 2008b).

When front-end grain fractionation is used before ethanol is produced, corn is usually degermed and dehulled and only the endosperm is used in ethanol production. This process results in production of either high-protein distillers dried grains (HP-DDG) or high-protein distillers dried grains with solubles (HP-DDGS). However, at this point, there is no commercial production of HP-DDGS, whereas there is a considerable production of HP-DDG (Widmer et al., 2007, 2008; Jacela et al., 2009; Kim et al., 2009).

The hulls that are removed from grain in the fractionation process are usually not used in swine feeding, but the corn germ that is extracted may be fed to pigs. Corn germ has a relatively high concentration of nonstarch polysaccharides with a total fat concentration of approximately 18% (Widmer et al., 2007).

If oil is extracted from the DDGS, a de-oiled DDGS that contains between 2% and 4% fat is produced (Jacela et al., 2007). Because of the low fat level in de-oiled DDGS, this product contains less energy than normal DDGS. Oil may also be removed by centrifugation, which is less efficient than removal by extraction, and a low-fat DDGS containing 7%–8% fat result from this process.

If fiber is removed from the DDGS, enhanced DDGS is obtained (Soares et al., 2008). This product contains approximately 10% less nonstarch polysaccharides than conventional DDGS and is expected to have a greater concentration of DE and ME than conventional DDGS.

14.3 CONCENTRATION AND DIGESTIBILITY OF NUTRIENTS IN ETHANOL COPRODUCTS

14.3.1 Carbohydrates

Production of ethanol or alcohol from grain is accomplished by fermentation of the starch fraction of the grain. All coproducts from the ethanol industry are, therefore, characterized by containing very little starch. The concentration of starch in DDGS produced from corn is approximately 7% (Stein and Shurson, 2009), whereas corn grain contains approximately 65% starch (Table 14.1).

Dietary fiber is the sum of carbohydrates and lignin that are resistant to digestion by mammalian enzymes in the small intestine, but that may be partially or completely fermented in the hindgut (AACC, 2001; IOM, 2006). Methods to measure dietary fiber include the crude fiber analysis (Mertens, 2003), the ADF and NDF procedures (Van Soest, 1963), and the total dietary fiber (TDF) procedure, which may separate dietary fiber into insoluble (IDF) and soluble dietary fiber (SDF; Prosky et al., 1984). An alternative to analyzing samples for dietary fiber is to calculate the concentration of organic residue (OR) in a feed ingredient by subtracting CP, ash, moisture, ether extract, sugar, and starch from 100 (de Lange, 2008).

TABLE 14.1
Chemical Composition of Corn, Sorghum, and Wheat, and Ethanol Coproducts Produced from Corn, Sorghum, and Wheat and Fed to Swine (As-Fed Basis)

	Grain or Coproduct										
Item	Corn	Sorghum	Wheat	Corn DDGS	Sorghum DDGS	Wheat DDGS	Corn DDG	Corn HP-DDG	De-oiled Corn DDGS	Enhanced Corn DDGS	Corn Germ
N	4	1	1	34	3	4	1	1	1	2	1
Gross energy (kcal/kg)	3891	3848	3830	4776	4334	4817	—	4989	—	4742	4919
Crude protein (%)	8.0	9.8	12.44	27.5	31.0	38.2	28.8	41.1	31.2	29.1	14.0
Calcium (%)	0.01	0.01	0.04	0.03	—	0.15	—	0.01	0.05	0.27	0.03
Phosphorus (%)	0.22	0.24	0.38	0.61	0.64	1.04	—	0.37	0.76	0.86	1.09
Crude fat (%)	3.3	—	2.0	10.2	7.7	3.6	—	3.7	4.0	10.8	17.6
Crude fiber (%)	—	—	2.4	6.6	9.8	7.6	—	—	—	—	—
Starch (%)	—	—	—	7.3	—	—	3.83	11.2	—	—	23.6
Neutral detergent fiber (%)	7.3	7.3	14.2	37.6	40.7	32.4	37.3	16.4	34.6	29.7	20.4
Acid detergent fiber (%)	2.4	3.8	2.9	11.1	22.8	17.0	18.2	8.7	16.1	8.7	5.6
Total dietary fiber (%)	—	—	—	31.8	32.2	—	43.0	—	—	25.2	—
Ash	0.9	—	—	3.8	3.6	4.8	—	3.2	4.64	—	3.3
Indispensable amino acids (%)											
Arginine	0.39	0.32	0.57	1.16	1.10	1.53	1.15	1.54	1.31	1.34	1.08
Histidine	0.23	0.23	0.29	0.72	0.71	0.92	0.68	1.14	0.82	0.75	0.41
Isoleucine	0.28	0.37	0.43	1.01	1.36	1.35	1.08	1.75	1.21	1.04	0.45
Leucine	0.95	1.25	0.83	3.17	4.17	2.66	3.69	5.89	3.64	3.26	1.06
Lysine	0.24	0.20	0.36	0.78	0.68	0.65	0.81	1.23	0.87	0.93	0.79
Methionine	0.21	0.18	0.21	0.55	0.53	0.53	0.56	0.83	0.58	0.58	0.25
Phenylalanine	0.38	0.47	0.53	1.34	1.68	1.92	1.52	2.29	1.69	1.38	0.57
Threonine	0.26	0.29	0.33	1.06	1.07	1.21	1.10	1.52	1.10	1.03	0.51
Tryptophan	0.09	0.07	0.16	0.21	0.35	0.40	0.22	0.21	0.19	0.19	0.12
Valine	0.38	0.48	0.55	1.35	1.65	1.70	1.39	2.11	1.54	1.40	0.71
Dispensable amino acids (%)											
Alanine	0.58	0.86	0.44	1.94	2.90	1.48	2.16	3.17	2.13	1.99	0.91
Aspartic acid	0.55	0.60	0.62	1.83	2.17	1.92	1.86	2.54	1.84	1.80	1.05

continued

TABLE 14.1 (continued)
Chemical Composition of Corn, Sorghum, and Wheat, and Ethanol Coproducts Produced from Corn, Sorghum, and Wheat and Fed to Swine (As-Fed Basis)

	Grain or Coproduct										
Item	Corn	Sorghum	Wheat	Corn DDGS	Sorghum DDGS	Wheat DDGS	Corn DDG	Corn HP-DDG	De-oiled Corn DDGS	Enhanced Corn DDGS	Corn Germ
N	4	1	1	34	3	4	1	1	1	2	1
Cystine	0.16	0.18	0.27	0.53	0.49	0.73	0.54	0.78	0.54	0.52	0.29
Glutamic acid	1.48	1.92	3.57	4.37	6.31	9.81	5.06	7.11	4.26	4.06	1.83
Glycine	0.31	0.29	0.50	1.02	1.03	1.62	1.00	1.38	1.18	1.11	0.76
Proline	0.70	0.77	1.14	2.09	1.40	4.11	2.50	3.68	2.11	1.99	0.92
Serine	0.38	0.37	0.48	1.18	2.50	1.88	1.45	1.85	1.30	1.25	0.56
Tyrosine	0.27	0.25	0.27	1.01	—	—	—	1.91	1.13	1.04	0.41

Source: Data from Bohlke, R. A. et al. *Journal of Animal Science* 83, 2396–2403, 2005; Stein, H. H. et al. *Journal of Animal Science* 84, 853–860, 2006; Stein, H. H. et al. *Asian Australian Journal of Animal Science* 22, 1016–1025, 2009; Feoli, C. et al. Digestible energy content of corn- vs. sorghum-based dried distillers grains with solubles and their effects on growth performance and carcass characteristics in finishing pigs. *Kansas State University Swine Day Report 2007*, pp. 131–136. Manhattan, KS: Kansas State University, 2007; Jacela, J. Y. et al. Amino acid digestibility and energy content of corn distillers meal for swine. *Kansas State University Swine Day Report 2007*, pp. 137–141. Manhattan, KS: Kansas State University, 2007; Jacela, J. Y. et al. *Journal of Animal Science* 87(E-Suppl. 3), 105, 2009; Pedersen, C. et al. *Journal of Animal Science* 85, 1168–1176, 2007a; Pedersen, C. et al. *Journal of Animal Science* 85, 2473–2483, 2007b; Widmer, M. R. et al. *Journal of Animal Science* 85, 2994–3003, 2007; Widyaratne, G. P., and R. T. Zijlstra. *Canadian Journal of Animal Science* 87, 103–114, 2007; Lan, Y. et al. *Animal Feed Science and Technology* 140, 155–163, 2008; Pahm, A. et al. *Journal of Animal Science* 86, 2180–2189, 2008a; Soares, J. A. et al. *Journal of Animal Science* 86(Suppl. 1), 522, 2008; Kim, B. G. et al. *Journal of Animal Science* 87, 4013–4021, 2009b; Urriola, P. E. et al. *Journal of Animal Science* 87, 2574–2580, 2009; Urriola, P. E. et al. *Journal of Animal Science* 88, 2373–2381, 2010; and Widyaratne, G. P. et al. *Canadian Journal of Animal Science* 89, 91–95, 2009.

Note: DDGS = distillers dried grains with solubles; DDG = distillers dried grains; and HP-DDG = high-protein distillers dried grain.

The concentration of the different fiber fractions is approximately three times greater in DDGS and DDG than in corn, but HP-DDG and HP-DDGS contain less fiber than DDG and DDGS because the corn was dehulled before fermentation (Guo et al., 2004). In contrast, the concentration of fiber in corn germ is greater than in DDGS because some of the fiber in corn is removed along with the mechanical removal of the germ. The digestibility of TDF in DDGS and in DDG is less than 35% in the small intestine and less than 50% over the entire gastrointestinal tract (Table 14.2). However, the digestibility of SDF in DDGS is greater than 90% (Urriola et al., 2010), which indicates that this fraction of fiber is easily digested by pigs. However, the digestibility of IDF is much less and as there is much more IDF than SDF in DDGS, this results in lower overall digestibility (Table 14.2). The fiber fraction, therefore, contributes relatively little to the energy value of these feed ingredients (Urriola et al., 2010). It is expected that the digestibility of fiber in other ethanol coproducts is equally low although this has not yet been confirmed.

The low digestibility of fiber in ethanol coproducts results in increased quantities of manure being excreted from pigs fed these products (Stein and Shurson, 2009). The overall digestibility of DM and fiber in diets containing ethanol coproducts is, therefore, reduced compared with diets containing only corn and soybean meal (Urriola and Stein, 2010). The digestibility of energy is also less in diets containing DDGS than in diets containing no DDGS (Urriola and Stein, 2010). Currently, much effort is directed towards developing feed additives such as enzymes or yeast products that can improve the digestibility of fiber in ethanol coproducts, but at this point, results have been disappointing (Jones et al., 2009). It is also possible that chemical treatment or processing of DDGS may result in improvement of the fiber digestibility. If the digestibility of the fiber in ethanol coproducts is improved, their energy value will also improve. It was recently reported that the apparent total tract digestibility (ATTD) of energy in DDGS increases after extrusion (Beltranena et al., 2009), which may be a result of increased fiber digestibility. Likewise, the ATTD of DM, OM, and energy is increased in diets containing DDGS if these diets are pelleted (Zhu et al., 2009), but it is not known if this is an effect of pelleting the DDGS or if it comes from the non-DDGS components of the diet. More research in this area is, therefore, needed.

TABLE 14.2
Concentration, Apparent Ileal Digestibility (AID), Apparent Total Tract Digestibility (ATTD), and Hindgut Fermentation of Different Fiber Fractions in Distillers Dried Grains with Solubles Produced from Corn (C), Sorghum (S), or a Blend of Corn and Sorghum (CS) Fed to Growing–Finishing Pigs

	Concentration (%)			AID (%)			ATTD (%)			Hindgut Fermentation (%)		
Item	C	S	CS	C	S	CS	C	S	CS	C	S	CS
N	8	1	1	8	1	1	8	1	1	8	1	1
Crude fiber	6.6	9.8	8.1	31.0	38.6	30.7	44.3	41.6	39.9	13.3	3.0	9.2
ADF	11.1	22.8	16.5	36.8	57.4	41.4	58.5	60.7	53.7	21.7	3.3	12.3
NDF	37.6	40.7	39.5	45.9	49.9	37.9	59.3	59.3	51.5	13.4	9.4	13.6
IDF[a]	30.7	34.1	35.4	20.0	27.7	4.8	40.3	41.3	28.6	20.3	13.6	23.8
SDF[a]	1.1	1.2	0.4	64.4	65.9	63.4	92.0	90.9	90.6	27.6	25.0	27.2
TDF[a]	31.8	32.2	35.8	28.9	33.4	15.9	49.5	48.8	39.2	20.6	15.4	23.3
OR[a]	46.5	45.6	46.9	58.6	41.6	32.9	77.1	72.5	68.4	18.5	30.9	35.5

Source: Data from Urriola, P. E. et al. *Journal of Animal Science* 88, 2373–2381, 2010.
[a] IDF = insoluble dietary fiber; SDF = soluble dietary fiber; TDF = total dietary fiber; and OR = organic residue.

14.3.2 Amino Acids

The concentration and standardized ileal digestibility of AA have been measured in 34 sources of corn DDGS, in one source of sorghum DDGS, and in two sources of wheat DDGS (Table 14.3). The results showed that even when the DDGS are produced from the same type of grain, some variation among different samples of DDGS exists for AA digestibility (Stein et al., 2006, 2009; Pahm et al., 2008a; Urriola et al., 2009). This is particularly true for Lys, which is more variable in digestibility than all other indispensable AA (Stein et al., 2006; Pahm et al., 2008a). Variability in the digestibility of AA is not related to the region within the United States where the DDGS is produced (Pahm et al., 2008a) and even if the DDGS is produced within a relatively small geographical region, large

TABLE 14.3
Standardized Ileal Digestibility of AA in Corn, Sorghum, and Wheat, and in Ethanol Coproducts Produced from Corn, Sorghum, and Wheat and Fed to Growing–Finishing Pigs

	Grain or Coproduct									
Item	Corn	Sorghum	Wheat	Corn DDGS	Sorghum DDGS	Wheat DDGS	Corn DDG	Corn HP-DDG	Corn Germ	De-oiled Corn DDGS
N	2	1	1	34	1	2	1	3	1	1
Indispensable amino acids (%)										
Arginine	87	70	88	81	78	86	83	83	83	82
Histidine	83	65	86	78	71	77	84	81	69	75
Isoleucine	81	66	84	75	73	80	83	81	57	75
Leucine	87	70	86	84	76	83	86	91	68	84
Lysine	72	57	75	62	62	57	78	64	58	50
Methionine	85	69	86	82	75	81	89	88	68	80
Phenylalanine	84	68	86	81	76	86	87	87	64	81
Threonine	74	64	79	71	68	75	78	77	53	66
Tryptophan	70	57	86	70	70	86	72	81	67	78
Valine	79	64	81	75	72	82	81	80	62	74
Dispensable amino acids (%)										
Alanine	83	69	76	78	73	68	82	86	64	77
Aspartic acid	80	66	78	69	68	57	74	76	60	61
Cystine	82	64	86	73	66	75	81	82	64	64
Glutamic acid	80	52	84	80	76	86	87	88	72	78
Glycine	84	71	92	63	67	68	66	75	76	53
Proline	96	50	105	74	83	81	55	73	84	73
Serine	83	72	88	76	73	77	82	84	65	73
Tyrosine	82	67	81	81	—	—	—	88	59	81

Source: Data from Bohlke, R. A. et al. *Journal of Animal Science* 83, 2396–2403, 2005; Stein, H. H. et al. *Journal of Animal Science* 84, 853–860, 2006; Stein, H. H. et al. *Asian Australian Journal of Animal Science* 22, 1016–1025, 2009; Jacela, J. Y. et al. Amino acid digestibility and energy content of corn distillers meal for swine. *Kansas State University Swine Day Report 2007*, pp. 137–141. Manhattan, KS: Kansas State University, 2007; Jacela, J. Y. et al. *Journal of Animal Science* 87(E-Suppl. 3), 105, 2009; Pedersen, C. et al. *Journal of Animal Science* 85, 2473–2483, 2007b; Widmer, M. R. et al. *Journal of Animal Science* 85, 2994–3003, 2007; Widyaratne, G. P., and R. T. Zijlstra. *Canadian Journal of Animal Science* 87, 103–114, 2007; Lan, Y. et al. *Animal Feed Science and Technology* 140, 155–163, 2008; Pahm, A. et al. *Journal of Animal Science* 86, 2180–2189, 2008a; Kim, B. G. et al. *Journal of Animal Science* 87, 4013–4021, 2009b; and Urriola, P. E. et al. *Journal of Animal Science* 87, 2574–2580, 2009.

Note: DDGS = distillers dried grains with solubles; DDG = distillers dried grains; and HP-DDG = high-protein distillers dried grains; AA = anino acids.

variations in Lys digestibility among sources of DDGS may be observed (Stein et al., 2009). The main reason for this variability is that some production units overheat the DDGS during drying, which results in Maillard type destruction of Lys (Pahm et al., 2008a, 2008b). This will result in a reduction in the total concentration of Lys as well as in Lys digestibility, but the concentration of crude protein will not be changed. In undamaged corn DDGS, the concentration of Lys as a percentage of CP is between 3.1% and 3.3%, but in heat-damaged corn DDGS, this percentage can be as low as 2.10% (Stein, 2007; Stein et al., 2009). It is, therefore, recommended that the concentration of Lys is measured before corn DDGS is used in diets fed to swine and if the concentration of Lys expressed as a percentage of CP is less than 2.80%, the DDGS should not be used in diets fed to swine.

Some of the variability in AA digestibility, and Lys digestibility in particular, is caused by the addition of solubles to the fermented grain because the solubles contain some residual sugars that were not fermented. The presence of these sugars will increase the likelihood of Maillard reactions occurring when the fermented grain is dried. The digestibility of AA in corn DDG is, therefore, greater than in corn DDGS, because the solubles are not added to the fermented grain when DDG is produced (Pahm et al., 2008a).

Most AA in corn DDGS have a digestibility that is approximately 10 percentage units less than corn, which may be a result of the greater concentration of dietary fiber in DDGS than in corn, because the presence of fiber in a feed ingredient usually reduces the digestibility of AA (Stein et al., 2007). However, except for Lys, the variability among different sources of corn DDGS is within the normal range of variation observed in other feed ingredients.

The digestibility of AA in corn HP-DDG is within the range of values measured for corn DDGS (Widmer et al., 2007; Jacela et al., 2009; Kim et al., 2009b). However, the digestibility of AA in corn germ is less than in corn DDG and corn DDGS. The reason for this may be that the proteins in corn germ are different from other proteins in the grain kernel (Widmer et al., 2007). The relatively high concentration of fiber in corn germ may also contribute to a reduction in AA digestibility.

Although sorghum has a lower digestibility of AA than corn (Pedersen et al., 2007b), sorghum DDGS has AA digestibilities that are within the range of values observed in corn DDGS (Urriola et al., 2009). However, AA digestibility data for only one source of sorghum DDGS has been reported. Likewise, the digestibility of most AA in wheat DDGS is similar to the values obtained in corn DDGS although the digestibility of Lys in wheat DDGS is less than in corn DDGS (Table 14.3). The digestibility of AA was measured in one source of de-oiled corn DDGS and all values were reported to be within the range of values for conventional corn DDGS (Jacela et al., 2008b).

14.3.3 Phosphorus

The P concentration in corn and sorghum is usually between 0.22% and 0.26%, but wheat contains between 0.35% and 0.40% P (Table 14.4). When starch is removed during fermentation, the concentration of minerals in the resulting DDGS is increased and the P concentration in corn DDGS and in sorghum DDGS is, therefore, between 0.60% and 0.80%, whereas wheat DDGS contains more than 1% P (Stein and Shurson, 2009; Widyaratne et al., 2009). When corn grain is dehulled and degermed, the majority of the P ends up in the germ fraction. Corn germ, therefore, contains approximately 1.10% P, whereas HP-DDG contains only 0.40% P (Widmer et al., 2007).

The majority of the P in cereal grains is bound in the phytate complex (Eeckhout and de Paepe, 1994). Pigs do not have the ability to break down the phytate complex in the small intestine where P absorption occurs, and the phytate bound P is excreted in the feces. The digestibility of P in corn and sorghum is, therefore, very low and values between 15% and 30% are usually measured for P digestibility in corn and sorghum (NRC, 1998; Bohlke et al., 2005; Pedersen et al., 2007a). The digestibility of P in wheat is, however, somewhat greater than in corn and sorghum because wheat contains intrinsic phytase that partially degrades the phytate complex before the end of the

TABLE 14.4
Concentration (%) and Apparent Total Tract Digestibility (ATTD) of P (%) in Cereal Grain and Ethanol Coproducts Fed to Growing–Finishing Pigs

	Grain or Coproduct						
Item	Corn	Sorghum	Wheat	Corn DDGS	Wheat DDGS	Corn HP-DDG	Corn Germ
N	4	1	1	15	4	1	1
Phosphorus (%)	0.22	0.24	0.38	0.61	1.04	0.37	1.09
ATTD, P (%)	25.00	25.00	30.00	58.90	51.90	59.60	28.60
ATTD, P (%) with phytase	57.80	—	45.00	71.00	—	—	—

Source: Data from Sauvant, D. et al. *Tables of Composition and Nutritional Value of Feed Materials*, 2nd ed. Wageningen Academic Publishers, 2004; Bohlke, R. A. et al. *Journal of Animal Science* 83, 2396–2403, 2005; Nyachoti, C. M. et al. *Journal of the Science of Food and Agriculture* 85, 2581–2586, 2005; Pedersen, C. et al. *Journal of Animal Science* 85, 1168–1176, 2007a; Widmer, M. R. et al. *Journal of Animal Science* 85, 2994–3003, 2007; Widyaratne, G. P., and R. T. Zijlstra. *Canadian Journal of Animal Science* 87, 103–114, 2007; Lan, Y. et al. *Animal Feed Science and Technology* 140, 155–163, 2008; Stein, H. H. et al. *Asian Australian Journal of Animal Science* 22, 1016–1025, 2009; Widyaratne, G. P. et al. *Canadian Journal of Animal Science* 89, 91–95, 200; and Almeida, F. N., and H. H. Stein. *Journal of Animal Science* 88: 2968–2977, 2010.

Note: DDGS = distillers dried grains with solubles; and HP-DDG = high-protein distillers dried grain.

small intestine, which increases the absorption of P from wheat (NRC, 1998; Zimmermann et al., 2002).

When corn, sorghum, or wheat is fermented, some of the phytate-bound phosphorus is believed to be released, and coproducts that have gone through fermentation, therefore, have a greater digestibility of P than corn (Stein and Shurson, 2009). The ATTD of P has been measured in 15 different sources of corn DDGS with an average value of 59% (Pedersen et al., 2007a; Stein et al., 2009; Almeida and Stein, 2010). In corn HP-DDG, which is also a fermented product, the ATTD of P is 59.6%, very close to the value measured for corn DDGS (Widmer et al., 2007). It appears, therefore, that the ATTD of P in corn coproducts that have been fermented is close to 59%. In contrast, in corn germ, which is not a fermented coproduct, the ATTD of P is only 28.60%, which is close to the values for corn (Widmer et al., 2007).

The ATTD of P in wheat DDGS was measured in four sources and an average value of 51.9% was reported (Nyachoti et al., 2005; Widyaratne and Zijlstra, 2007; Widyaratne et al., 2009). It is, therefore, apparent that the increase in P digestibility in wheat compared with corn is not maintained during fermentation and in fermented DDGS products, this digestibility is actually slightly greater in corn DDGS than in wheat DDGS.

The effect of adding microbial phytase to corn DDGS was measured in one experiment (Almeida and Stein, 2010) and it was shown that the ATTD of P in corn DDGS is 71% when microbial phytase was included in the diet. At this point, there are no reports on the effects of adding microbial phytase to other ethanol coproducts, but work to address this question is currently being conducted at the University of Illinois.

Because of the greater digestibility of P in DDGS than in corn and soybean meal, the need for adding inorganic phosphorus sources is reduced when DDGS is included in the diet. The excretion of P from the pigs, will therefore, also be reduced without reducing performance (Almeida and Stein, 2010).

The availability of P in feed ingredients is sometimes measured as the relative bioavailability of phosphorus rather than the ATTD (Cromwell, 1992). While data for the relative availability of P have been measured in most commonly used feed ingredients, they are not always useful in feed formulation because they are not always additive in mixed diets as different standards have been used to measure availability.

The relative availability of P in corn DDGS has, however, been measured and values between 70% and 90% have been reported in experiments where dicalcium phosphate was used as a standard (Burnell et al., 1989; Whitney and Shurson, 2001; Jenkin et al., 2007). These values correspond to ATTD between 56% and 72%, which are close to those of P measured in corn DDGS. There is, therefore, good agreement between the two different types of measurements, but for practical feed formulation, it is suggested that values for ATTD of P in feed ingredients should be used.

14.3.4 Ether Extract

The apparent ileal and the true ileal digestibility of ether extract in corn, DDGS, HP-DDG, and corn germ has been reported from one experiment (Kim et al., 2009a). Results of this experiment showed that the apparent ileal digestibility of ether extract is between 50% and 60% and the true ileal digestibility of ether extract is between 50% and 76% in DDGS, HP-DDG, and corn germ (Table 14.5). The ATTD of ether extract in DDGS was also measured by Stein et al. (2009) and reported at 70%. There is, however, a need for more information in this area because the relatively high concentrations of ether extract in DDGS and other ethanol coproducts may result in production of pork with soft fat. Soft and unsaturated fat is produced if pigs are fed diets containing relatively high amounts of unsaturated fat (Madsen et al., 1992), which may be the case if DDGS is included in the diets.

14.4 CONCENTRATION AND DIGESTIBILITY OF ENERGY IN ETHANOL COPRODUCTS

The concentration of energy is greater in DDGS and in most other corn-based ethanol coproducts than in corn (Table 14.6). However, the concentration of fiber in ethanol coproducts is greater than in corn and because of the low digestibility of energy in fiber (Urriola et al., 2010), the digestibility of energy is also less in DDGS and other ethanol coproducts than in corn. The concentration of digestible and metabolizable energy in corn DDGS is, therefore, not greater than in corn (Pedersen et al., 2007a; Stein et al., 2009). The same is the case for corn germ, which also has a similar concentration of digestible and metabolizable energy as corn (Widmer et al., 2007). However, HP-DDG has a reduced concentration of fiber compared with DDGS and corn germ, and the concentration of digestible and metabolizable energy in HP-DDG is, therefore, greater than in corn (Widmer et al., 2007; Kim et al., 2009b). In contrast, in de-oiled DDGS, the fiber is left and the oil is removed.

TABLE 14.5
True Digestibility of Ether Extract in Corn and Ethanol Coproducts Fed to Growing–Finishing Pigs

	Grain or Coproduct			
Item	Corn	Corn DDGS	Corn HP-DDG	Corn Germ
N	1	1	1	1
True ileal digestibility (%)	53.0	62.1	76.5	50.1
True total tract digestibility (%)	41.4	51.9	70.2	43.9

Source: Unpublished data from the University of Illinois.

Note: DDGS = distillers dried grains with solubles; and HP-DDG = high-protein distillers dried grain.

TABLE 14.6
Concentration of Energy in Corn, Sorghum, and Wheat and in Ethanol Coproducts Produced from Corn, Sorghum, and Wheat Fed to Growing–Finishing Pigs

	Grain or Coproduct								
Item Ingredient	**Corn**	**Sorghum**	**Wheat**	**Corn DDGS**	**Sorghum DDGS**	**Wheat DDGS**	**Corn HP-DDG**	**Corn Germ**	**De-oiled Corn DDGS**
N	**2**	**—**	**—**	**10**	**2**	**—**	**2**	**1**	1
Gross energy (kcal/kg DM)	4458	—	—	5434	4908	—	5553	5335	4090
Apparent total tract digestibility (%)	90.0	87.0	88.0	76.8	76.0	74.0	89.4	74.6	66.5
Digestible energy (kcal/kg DM)	4072	3798	3827	4140	3459	3581	4903	3979	2719
Metabolizable energy (kcal/kg DM)	3981	3753	3648	3897	—	3346	4583	3866	2506

Sources: Data from NRC. *Nutrient Requirements of Swine*, 10th rev. ed. National Academies Press, 1998; Sauvant, D. et al. *Tables of Composition and Nutritional Value of Feed Materials*, 2nd ed. Wageningen Academic Publishers, 2004; Feoli, C. et al. Digestible energy content of corn- vs. sorghum-based dried distillers grains with solubles and their effects on growth performance and carcass characteristics in finishing pigs. *Kansas State University Swine Day Report 2007*, pp. 131–136. Manhattan, KS: Kansas State University, 2007; Pedersen, C. et al. *Journal of Animal Science* 85, 1168–1176, 2007a; Widmer, M. R. et al. *Journal of Animal Science* 85, 2994–3003, 2007; Jacela, J. Y. et al. *Journal of Animal Science* 86(E-Suppl. 3), 87–88, 2008b; and Kim, B. G. et al. *Journal of Animal Science* 87, 4013–4021, 2009b.

Note: DDGS = distillers dried grains with solubles; and HP-DDG = high-protein distillers dried grain.

De-oiled corn DDGS, therefore, contains only 2719 and 2506 kcal digestible and metabolizable energy, respectively (Jacela et al., 2008b).

The concentration of digestible energy in sorghum DDGS has been measured in one experiment and it was reported that sorghum DDGS contained approximately 220 kcal/kg (as-is basis) less digestible energy than corn DDGS (Feoli et al., 2007). The reduced concentration of digestible energy in sorghum DDGS may be a result of a reduced concentration of ether extract when compared with corn DDGS.

14.5 INCLUSION OF ETHANOL COPRODUCTS IN DIETS FED TO SWINE

14.5.1 Inclusion of Ethanol Coproducts in Diets Fed to Weanling Pigs

Effects of including corn DDGS in diets fed to weanling pigs have been investigated in 12 experiments (Table 14.7). In one experiment, only 10% DDGS was included in the diet and this level of inclusion did not significantly affect pig performance (Linneen et al., 2006), which is in agreement with data showing that 20% corn DDGS can be used in diets fed to weanling pigs (Senne et al., 1995; Almeida and Stein, 2010). Likewise, in two titration experiments, effects of adding 0%, 5%, 10%, 15%, 20%, or 25% DDGS to diets fed to weanling pigs from 4 days after weaning were investigated and no impact of DDGS level was observed (Whitney and Shurson, 2004). Up to 30% inclusion of DDGS in nursery diets were also reported to not influence performance if DDGS was introduced in the diets from 2 to 3 weeks postweaning (Gaines et al., 2006; Spencer et al., 2007; Barbosa et al., 2008; Burkey et al., 2008). Of the 12 experiments, which evaluated effects of adding DDGS to weanling pig diets, none reported a reduction in average daily gain (ADG), when DDGS was introduced no sooner than 2 to 3 weeks postweaning. The average daily feed intake (ADFI) was reduced in two experiments as DDGS was included in the diet (Gaines et al., 2006; Barbosa et al., 2008), but the gain to feed ratio (G:F) was improved when DDGS was added to the diet in five of the 12 experiments (Gaines et al., 2006; Spencer et al., 2007; Barbosa et al., 2008). Pig mortality was reported in two experiments and no differences between pigs fed DDGS containing diets and pigs fed control diets were observed. Based on these data it was concluded that weanling pigs may be fed diets containing up to 30% DDGS from 2 to 3 weeks postweaning. Inclusion of up to 30% de-oiled corn DDGS in diets fed to weanling pigs also results in no change in ADFI, ADG, and G:F (Jacela et al., 2008a).

TABLE 14.7
Effects of Including Corn Distillers Dried Grains with Solubles (DDGS) in Diets Fed to Weanling Pigs

		Response to Dietary Corn DDGS		
Item	**N**	**Increased**	**Reduced**	**Not Changed**
ADG	12	0	0	12
ADFI	12	0	4	8
G:F	12	5	0	7
Mortality	2	0	0	2

Source: Data calculated from experiments by Senne, B. W. et al. Effects of distillers grains on growth performance in nursery and finishing pigs. *Kansas State University Swine Day Report*, pp. 68–71. Manhattan, KS: Kansas State University, 1995; Whitney, M. H., and G. C. Shurson. *Journal of Animal Science* 82, 122–128, 2004; Gaines, A. et al. *Journal of Animal Science* 84 (Suppl. 2), 120, 2006; Linneen, S. K. et al. Effects of dried distillers grain with solubles on nursery pig performance. *Kansas State University Swine Day Report*, pp. 100–102. Manhattan: Kansas State University, 2006; Spencer, J. D. et al. *Journal of Animal Science* 85(Suppl. 2), 96–97, 2007; Barbosa, F. F. et al. *Journal of Animal Science* 86(Suppl. 1): 446, 2008; Burkey, T. E. et al. *Journal of Animal Science* 86(Suppl. 2), 50, 2008; and Almeida, F. N., and H. H. Stein. *Journal of Animal Science* 88, 2968–2977, 2010.

Inclusion of sorghum DDGS in diets fed to weanling pigs has been investigated in three experiments, and results from one experiment suggest that it may be possible to include 30% sorghum DDGS in diets fed to weanling pigs without reducing pig performance (Senne et al. 1996). However, later results indicate that inclusion of 30% sorghum DDGS in diets fed to weanling pigs may reduce performance (Feoli et al., 2008). Differences in the quality of sorghum DDGS used in these experiments may be the reason for the different results observed among experiments and at this time, it is recommended that diets fed to weanling pigs contain no more than 20% sorghum DDGS.

There have been no experiments conducted to investigate the effects of including ethanol coproducts other than DDGS and de-oiled DDGS in diets fed to weanling pigs. It is, therefore, unknown if HP-DDG, corn germ, or other coproducts can be used in these diets.

14.5.2 Inclusion of Ethanol Coproducts in Diets Fed to Growing-Finishing Pigs

14.5.2.1 Effects of Ethanol Coproducts on Live Pig Performance

Data from a total of 32 experiments have been reported in which corn DDGS was fed to growing–finishing pigs (Table 14.8). In most of these experiments, no change in ADG, ADFI, and G:F has been reported. There are, however, some experiments that reported reduced performance as DDGS

TABLE 14.8
Effects of Including Corn Distillers Dried Grains with Solubles (DDGS) in Diets Fed to Growing–Finishing Pigs

		Response to Dietary Corn DDGS		
Item	N	Increased	Reduced	Not Changed
ADG	31	1	7	23
ADFI	29	2	7	20
G:F	31	4	6	21
Dressing percentage	21	0	10	11
Backfat (mm)	19	0	4	15
Lean meat (%)	18	0	1	17
Loin depth (cm)	17	0	3	14
Belly thickness (cm)	4	0	2	2
Belly firmness	3	0	3	0
Iodine value	9	8	0	1

Source: Data calculated from experiments by Gralapp et al. (2002), Fu et al. (2004), Cook et al. (2005), DeDecker et al. (2005), Whitney et al. (2006), McEwen (2006, 2008), Gaines et al. (2007a, 2007b), Gowans et al. (2007), Hinson et al. (2007), Jenkin et al. (2007), White et al. (2007), Widyaratne and Zijlstra (2007), Xu et al. (2007a, 2007b, 2008a, 2008b), Augspurger et al. (2008), Drescher et al. (2008, 2009), Duttlinger et al. (2008), Hill et al. (2008a), Linneen et al. (2008), Stender and Honeyman (2008), Weimer et al. (2008), Widmer et al. (2008), Amaral et al. (2009), Cromwell et al. (2009), Hilbrands et al. (2009), Lammers et al. (2009), and Stevens et al. (2009).

was included in the diets. The reason for this difference may be that if DDGS of poor quality is used, pig performance may be reduced, whereas good quality DDGS does not reduce performance (Drescher et al., 2009). The inclusion rate of DDGS in the experiments that were reported varied from 5% to 60%, but most experiments used 30% DDGS or less. In some of the experiments with 30% inclusion, no difference in performance was observed (Cook et al., 2005; DeDecker et al., 2005; Xu et al., 2007a). Lower inclusion rates have also been used without influencing pig performance (Gowans et al., 2007; Jenkin et al., 2007; Linneen et al., 2008; Amaral et al., 2009; Drescher et al., 2009; Hilbrand et al., 2009; Lammers et al., 2009; Stevens et al., 2009). However, data from other experiments in which 10%, 20%, or 30% DDGS was included in diets fed to growing–finishing pigs showed a linear reduction in live pig performance (Fu et al., 2004; Whitney et al., 2006; Linneen et al., 2008; Weimer et al., 2008). The reduced performance that is sometimes observed from pigs fed diets containing DDGS may be a result of reduced palatability, because pigs prefer to eat diets containing no DDGS (Hastad et al., 2005; Seabolt et al., 2010). It is also possible that in some of the experiments in which reduced performance was observed, diets were formulated based on the concentration of total AA rather than on digestible AA, which may lead to a reduced performance. Diets that contain DDGS may also be deficient in tryptophan (Trp) because DDGS has a low concentration of Trp. It may, therefore, sometimes be necessary to also include crystalline Trp in diets containing DDGS (Stein, 2007).

Based on the wide body of literature that is available on feeding corn DDGS to growing–finishing pigs, it is concluded that in most cases, at least 20% and probably 30% DDGS can be included in growing–finishing pig diets. At these inclusion levels, pig performance is usually not influenced by DDGS provided that a high-quality source of DDGS is used and diets are properly formulated.

Conclusions from eight experiments in which sorghum DDGS was included in diets fed to growing–finishing pigs also led to the conclusion that 30% sorghum DDGS may be used. At this inclusion rate, ADG, ADFI, and G:F are not reduced (Senne et al., 1996). However, if greater inclusion rates are used, pig performance will be reduced (Senne et al., 1996; Feoli et al., 2008).

Inclusion of corn HP-DDG in diets fed to growing–finishing pigs was reported in two experiments (Widmer et al., 2008; Kim et al., 2009b). In the experiment by Widmer et al. (2008), pigs were fed HP-DDG from 22 kg to market, whereas in the experiment by Kim et al. (2009b), pigs were fed diets containing HP-DDG only in the early and late finishing stages. In both experiments, no overall effects of HP-DDG on pig performance were observed. It was, therefore, concluded that corn HP-DDG may be included in corn-based diets fed to growing–finishing pigs at levels needed to replace all the soybean meal in the diets provided that crystalline AA are included in concentrations necessary to balance all indispensable AA.

Corn germ was also included in diets fed to growing–finishing pigs in the experiment by Widmer et al. (2008). Diets containing 5% or 10% corn germ, but no other ethanol coproducts, were used in all three stages of growth. A linear increase in the final weight of the pigs was observed as corn germ was included in the diets and a tendency for increased daily gain was observed with diets containing corn germ. It was, therefore, concluded that growing–finishing pigs will improve performance if they are fed diets containing 10% corn germ (Widmer et al., 2008). It is possible that greater inclusion rates for corn germ can be used, but research to investigate this possibility needs to be conducted. There have been no reports of experiments in which other ethanol coproducts were fed to growing–finishing pigs.

14.5.2.2 Effects of Ethanol Coproducts on Carcass Composition and Quality

The most consistent effect of including DDGS in diets fed to finishing pigs is that they will produce fat that is less saturated than if no DDGS is used. The reason for this is that DDGS contains approximately 10% fat, which consists of mainly unsaturated fatty acids. More information about specific lipids can be found in Chapter 8. When pigs are fed DDGS, they will, therefore, deposit more unsaturated fat, which results in softer body fat depots. This can be observed in the form of softer bellies and softer backfat when pigs are processed, which may reduce their value. Softness of fat in pigs is often assessed by measuring the so-called iodine values. Iodine values have been measured in nine experiments in which DDGS was included in the diets fed to finishing pigs, and in eight of these nine experiments, an increase in iodine value was reported. This observation indicates that the fat was softer in pigs fed DDGS than in pigs fed no DDGS. To correct this problem, DDGS may be withdrawn from the diets during the final 2 to 4 weeks before harvest, which can result in acceptable iodine values (Hill et al., 2008a; Xu et al., 2008b).

Reduced dressing percentage of pigs fed corn DDGS containing diets has also been reported in some of the experiments in which corn DDGS were fed to growing–finishing pigs (Cook et al., 2005; Whitney et al., 2006; Feoli et al., 2007; Gaines et al., 2007a, 2007b; Hinson et al., 2007; Xu et al., 2007a; Linneen et al., 2008; Weimer et al., 2008; Drescher et al., 2009; Stevens et al., 2009). However, in many other experiments, no effects of DDGS on dressing percentage were reported (Fu et al., 2004; McEwen, 2006, 2008; Xu et al., 2007b; Augspurger et al., 2008; Drescher et al., 2008; Hill et al., 2008a; Stender and Honeyman, 2008; Widmer et al., 2008; Hilbrands et al., 2009). Thus, a reduced dressing percentage was reported only in 10 of the 21 experiments conducted. Pigs that are fed diets containing sorghum DDGS also sometimes have no change in dressing percentage while at other times, differences may be observed (Senne et al., 1996, 1998; Feoli et al., 2007). At this point, it is not clear what the reason for these differences are, but increased concentrations of fiber and protein may be contributing factors (Kass et al., 1980; Ssu et al., 2004).

Other carcass quality measures such as backfat thickness, lean meat percentage, and loin depth are not influenced by the inclusion of corn DDGS in the diets. Belly thickness has been reported to decrease in some, but not all, experiments in which corn or sorghum DDGS was included in the diet. Pigs fed diets containing corn HP-DDG may also have softer bellies and increased iodine values compared with pigs fed corn–soybean meal diets (Widmer et al., 2008), but pigs fed diets containing corn germ have firmer bellies and reduced iodine values (Widmer et al., 2008).

The palatability of pork from pigs fed up to 20% corn DDGS, up to 40% corn HP-DDG, or up to 10% corn germ was measured in one experiment (Widmer et al., 2008). It was reported from this experiment that the overall acceptance of pork from pigs fed diets containing ethanol coproducts is not different from that of pigs fed corn–soybean meal diets. It is, therefore, unlikely that consumers will be able to tell whether or not the pork they are eating come from a pig that was fed ethanol coproducts or not.

14.5.3 Inclusion of Ethanol Coproducts in Diets Fed to Sows

Gestating sows may be fed diets containing up to 50% corn DDGS without any negative impacts on performance measured as farrowing rate, litter weight, lactation performance, and return to estrus (Wilson et al., 2003). It is, however, possible that litter size is increased if DDGS is included in the diet for at least two parities (Wilson et al., 2003), which may be a result of the increased fiber concentration in DDGS containing diets compared with corn–soybean meal diets.

Diets fed to lactating sows may include up to at least 30% DDGS without negatively influencing sow or litter performance (Song et al., 2007a; Greiner et al., 2008), but experiments to measure the effects of using greater inclusion rates have not been conducted. The concentration of P in the manure from sows fed diets containing DDGS is also reduced compared with sows fed no DDGS (Hill et al., 2008b). There is no influence of adding corn DDGS to a corn–soybean meal-based diet on milk composition, apparent nitrogen digestibility, or nitrogen retention, but sows fed diets containing 20% or 30% corn DDGS have reduced values for blood urea nitrogen compared with sows fed a corn–soybean meal diet (Song et al., 2007b). It is, therefore, possible that sows fed DDGS containing diets receive a better balance of AA compared with sows fed the control diet. Sows fed diets containing DDGS also have a greater weight gain during lactation than those fed diets containing no DDGS (Greiner et al., 2008), which indicates that sows may digest the fiber in DDGS better than growing pigs, and therefore, are able to absorb more energy from DDGS.

There are no data on inclusion of HP-DDG, de-oiled DDGS, or corn germ in diets fed to sows. Likewise, the effects of adding wheat DDGS or sorghum DDGS have not been reported. It is, therefore, not known how much wheat DDGS or sorghum DDGS may be included in diets fed to sows, but it is expected that the responses to sorghum DDGS and wheat DDGS are similar to those observed for corn DDGS.

14.6 CONCLUSIONS

Many experiments have been conducted in recent years to elucidate the effects of adding DDGS to diets fed to swine. Although the results of these experiments are somewhat variable, it is concluded that with the exception of the initial 2 to 3 weeks postweaning, pigs may be fed diets containing up to 30% DDGS. Gestating sows may be fed up to 50% DDGS and lactating sows may also be fed at least 30% DDGS. At these inclusion levels, pig performance will likely not change provided that a source of DDGS of reasonable quality is used. It is, however, documented that pigs fed DDGS will have softer fat and greater iodine values and it may, therefore, be necessary to withdraw or reduce the inclusion rate of DDGS in diets during the late finishing period.

All the soybean meal in diets fed to growing and finishing pigs may be replaced by HP-DDG without any change in performance. Likewise, corn germ may be included at a concentration of at least 10% in growing–finishing diets.

Diets containing DDGS will usually contain the same amount of metabolizable energy as diets containing no DDGS. The inclusion of inorganic P in DDGS containing diets can, however, be reduced because DDGS has a much greater concentration of digestible P than corn and soybean meal. Diets that include DDGS need to be formulated on the basis of standardized ileal digestible AA and all indispensable AA need to be included at required levels. It is, therefore, necessary that diets containing DDGS or other biofuels coproducts are fortified with crystalline AA. Some sources of DDGS have been observed to contain less AA than average and DDGS of such qualities should

not be used in diets fed to swine. In conclusion, DDGS and other coproducts from the ethanol industry are excellent feed ingredients that easily can be incorporated into diets fed to pigs if a few basic principles in diet formulations are observed. DDGS and other coproducts from the ethanol industry can also be used in poultry diets, as is discussed in Chapter 15.

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