Chapter 4

Use of Distillers Co-products in Diets Fed to Swine

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Distillers co-products have been used in swine feeding for more than fifty years, but the emergence of the fuel ethanol industry during the last few decades has dramatically increased the total quantities of distillers co-products that are available to the livestock and poultry industries. New technologies have also allowed the industry to convert a greater proportion of the carbohydrates in the grain to ethanol, which in turn has resulted in distillers co-products that have a different composition than the products produced earlier. Different technologies used in the production process allow for upstream or downstream fractionation of the grain or the co-products, which results in a number of different co-products. For the swine industry to use the co-products most efficiently, research must be conducted to measure the nutritional value of these co-products in terms of energy and nutrient digestibility. The next step is to determine the inclusion rates of distillers co-products in diets fed to different categories of pigs that will result in the greatest performance without reducing the quality of the final products. If there are other consequences of including distillers co-products in swine diets, these also need to be documented for each product.

Distillers Co-products Used in Diets Fed to Swine

The co-products produced from the distillation of grain vary in composition according to the sources of grain that were used in the fermentation. In the United States, most distillers co-products are produced from corn, but sorghum is also used in some units (Urriola et al., 2007). Distillers co-products may be produced from fuel ethanol production or from beverage production; the nutritional value is not influenced by the type of plant used (Pahm et al., 2008). Likewise, the region within the United States in which the co-products are produced does not influence the composition or the quality of the co-products (Pahm et al., 2008).

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The most common co-product is distillers dried grains with solubles (DDGS), which by definition is a product that contains all the distillers grains and at least 70% of the condensed solubles produced after fermentation. If no solubles are added, the product is called distillers dried grains (DDG). If the grain is de-hulled and de-germed prior to fermentation, high protein distillers dried grains with solubles are produced (HP-DDGS). This product contains less fat and less fiber but more protein than conventional DDGS. If the solubles are not added back to the distilled grains, high protein distillers dried grains are produced (Widmer, McGinnis, and Stein, 2007). The corn germ that is extracted from corn during de-germing can also be fed to pigs, but this product has a relatively high concentration of non-starch polysaccharides (Widmer, McGinnis, and Stein, 2007). If oil is extracted from the DDGS, de-oiled DDGS are produced (Jacela et al., 2007). De-oiled DDGS contain less ether extract and therefore also less energy than conventional DDGS. If fiber is removed from the DDGS after production, a product called enhanced DDGS is produced (Soares et al., 2008). This product contains approximately 10% less nonstarch polysaccharides than conventional DDGS.

Nutrient and Energy Composition and Digestibility in Distillers Co-products

Concentration and Digestibility of Carbohydrates

Most cereal grains contain between 60% and 70% starch, which is easily digested by pigs and absorbed in the form of glucose. However, production of alcohol from grain requires that the grain is fermented, and most of the starch in the grain is converted into alcohol during this process. All distillers co-products therefore have a low concentration of starch, whereas the concentration of most other nutrients usually is greater than in the original grain (Table 4.1). The concentrations of carbohydrates in distillers co-products are therefore lower than in cereal grains, and most of the carbohydrates are non-starch polysaccharides (fiber). The concentration of the different fiber fractions (neutral detergent fiber, acid detergent fiber, and total dietary fiber) 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 is de-hulled before fermentation. The digestibility of fiber in DDGS and in DDG is less than 20% in the small intestine and less than 50% over the entire gastro-in-

Table 4.1. Chemical composition of corn, sorghum, and distillers co-products produced from corn and sorghum (as-fed basis)

	Grain or Co-product								
Item	**Corn**	**Sorghum**	**Corn DDGS**	**Sorghum DDGS**	**Corn DDG**	**Corn HP-DDG**	**De-oiled Corn DDGS**	**Enhanced Corn DDGS**	**Corn Germ**
N	**4**	**1**	**34**	**3**	**1**	**1**	**1**	**2**	**1**
Gross energy, kcal/kg	3,891	3,848	4,776	4,334	-	4,989	-	4,742	4,919
Crude protein, %	8.0	9.8	27.5	31.0	28.8	41.1	31.2	29.1	14.0
Calcium, %	0.01	0.01	0.03	-	-	0.01	0.05	0.27	0.03
Phosphorus, %	0.22	0.24	0.61	0.64	-	0.37	0.76	0.86	1.09
Crude fat, %	3.3	-	10.2	7.7	-	3.7	4.0	10.8	17.6
Crude fiber, %	-	-	-	7.2	-	-	-	-	-
Starch, %	-	-	7.3	-	3.83	11.2	-	-	23.6
Neutral detergent fiber, %	7.3	7.3	25.3	34.7	37.3	16.4	34.6	29.7	20.4
Acid detergent fiber, %	2.4	3.8	9.9	25.3	18.2	8.7	16.1	8.7	5.6
Total dietary fiber, %	-	-	42.1	-	-	-	-	25.2	-
Ash	0.9	-	3.8	3.6	-	3.2	4.64	-	3.3
Indispensable amino acids, %									
Arginine	0.39	0.32	1.16	1.10	1.15	1.54	1.31	1.34	1.08
Histidine	0.23	0.23	0.72	0.71	0.68	1.14	0.82	0.75	0.41
Isoleucine	0.28	0.37	1.01	1.36	1.08	1.75	1.21	1.04	0.45
Leucine	0.95	1.25	3.17	4.17	3.69	5.89	3.64	3.26	1.06
Lysine	0.24	0.20	0.78	0.68	0.81	1.23	0.87	0.93	0.79
Methionine	0.21	0.18	0.55	0.53	0.56	0.83	0.58	0.58	0.25
Phenylalanine	0.38	0.47	1.34	1.68	1.52	2.29	1.69	1.38	0.57

Table 4.1. Continued

	Grain or Co-product								
Item	**Corn**	**Sorghum**	**Corn DDGS**	**Sorghum DDGS**	**Corn DDG**	**Corn HP-DDG**	**De-oiled Corn DDGS**	**Enhanced Corn DDGS**	**Corn Germ**
N	**4**	**1**	**34**	**3**	**1**	**1**	**1**	**2**	**1**
Phenylalanine	0.38	0.47	1.34	1.68	1.52	2.29	1.69	1.38	0.57
Threonine	0.26	0.29	1.06	1.07	1.10	1.52	1.10	1.03	0.51
Tryptophan	0.09	0.07	0.21	0.35	0.22	0.21	0.19	0.19	0.12
Valine	0.38	0.48	1.35	1.65	1.39	2.11	1.54	1.40	0.71
Dispensable amino acids, %									
Alanine	0.58	0.86	1.94	2.90	2.16	3.17	2.13	1.99	0.91
Aspartic acid	0.55	0.60	1.83	2.17	1.86	2.54	1.84	1.80	1.05
Cysteine	0.16	0.18	0.53	0.49	0.54	0.78	0.54	0.52	0.29
Glutamic acid	1.48	1.92	4.37	6.31	5.06	7.11	4.26	4.06	1.83
Glycine	0.31	0.29	1.02	1.03	1.00	1.38	1.18	1.11	0.76
Proline	0.70	0.77	2.09	1.40	2.50	3.68	2.11	1.99	0.92
Serine	0.38	0.37	1.18	2.50	1.45	1.85	1.30	1.25	0.56
Tyrosine	0.27	0.25	1.01	-	-	1.91	1.13	1.04	0.41

Sources: Data from Bohlke, Thaler, and Stein, 2005; Feoli et al., 2007; Jacela et al., 2007; Pedersen, Boersma, and Stein, 2007a,b; Urriola et al., 2007; Widmer, McGinnis, and Stein, 2007; Pahm et al., 2008; and Soares et al., 2008.

testinal tract, and the fiber fraction, therefore, contributes relatively little to the energy value of these products. The digestibilities of fiber in other distillers co-products are thought to be equally low although they have not been measured.

The low digestibility of fiber in distillers co-products results in increased quantities of manure being excreted from pigs fed these products, and the overall dry matter digestibility of diets containing distillers co-products is lower than in corn-based diets (Pedersen, Boersma, and Stein, 2007a). Currently, much effort is being directed toward developing feed additives such as enzymes or yeast products that can improve the digestibility of fiber in distillers co-products. If the digestibility improves, the energy value of these products will also improve.

Digestibility of Amino Acids

The digestibility of most amino acids in DDGS (Table 4.2) is approximately 10 percentage units lower than in corn (Fastinger and Mahan, 2006; Stein et al., 2006; Pahm et al., 2008). The lower digestibility of amino acids in DDGS compared with that in corn may be a result of the greater concentration of fiber in DDGS than in corn, because dietary fiber reduces amino acid digestibility. The variability in digestibility of amino acids among sources of corn DDGS is also greater than among sources of corn, which may be due to differences in production technologies and procedures among plants producing DDGS (Pahm et al., 2008). However, variability in digestibility of amino acids is not related to the region within the United States where the DDGS are produced (Pahm et al., 2008).

The variability in the concentration and digestibility of lysine in DDGS is greater than the variability in digestibility of most other amino acids. The main reason is that some production units overheat the DDGS during drying, which results in Maillard-type destruction of lysine (Pahm et al., 2008). This will result in a reduction in the total concentration of lysine as well as in the digestibility of lysine, but the concentration of crude protein will not be changed. In un-damaged DDGS, the concentration of lysine as a percentage of crude protein is between 3.1% and 3.3%, but in heat-damaged DDGS, this percentage can be as low as 2.10% (Stein, 2007). Therefore, the concentration of lysine should be measured before using DDGS in diets fed to swine, and if the concen-

Table 4.2. Standardized ileal digestibility of amino acids in corn, sorghum, and distillers co-products produced from corn and sorghum

Item	Corn	Sorghum	Corn DDGS	Sorghum DDGS	Corn DDG	Corn HP-DDG	Corn Germ	De-oiled Corn DDGS
N	**2**	**1**	**34**	**1**	**1**	**1**	**1**	**1**
Indispensable amino acids, %								
Arginine	87	70	81	78	83	83	83	823
Histidine	83	65	78	71	84	81	69	75
Isoleucine	81	66	75	73	83	81	57	75
Leucine	87	70	84	76	86	91	68	84
Lysine	72	57	62	62	78	64	58	50
Methionine	85	69	82	75	89	88	68	80
Phenylalanine	84	68	81	76	87	87	64	81
Threonine	74	64	71	68	78	77	53	66
Tryptophan	70	57	70	70	72	81	67	78
Valine	79	64	75	72	81	80	62	74
Dispensable amino acids, %								
Alanine	83	69	78	73	82	86	64	77
Aspartic acid	80	66	69	68	74	76	60	61
Cysteine	82	64	73	66	81	82	64	64
Glutamic acid	80	52	80	76	87	88	72	78
Glycine	84	71	63	67	66	75	76	53
Proline	96	50	74	83	55	73	84	73
Serine	83	72	76	73	82	84	65	73
Tyrosine	82	67	81	-	-	88	59	81

Sources: Data from Bohlke, Thaler, and Stein, 2005; Jacela et al., 2007; Pedersen, Boersma, and Stein, 2007b; Stein, 2007; Urriola et al., 2007; Widmer, McGinnis, and Stein, 2007; and Pahm et al., 2008.

tration of lysine expressed as a percentage of crude protein is less than 2.80%, the DDGS should not be used (Stein, 2007).

Some of the variability in amino acid digestibility, and lysine digestibility in particular, is caused by the addition of solubles to the distilled grain because the solubles contain some residual sugars that are not fermented in the process. The presence of these sugars will increase the likelihood of Maillard reactions occurring when the distilled grain is dried. The digestibility of amino acids in DDG is, therefore, greater than in DDGS, because the solubles are not added to the distilled grain when producing DDG (Pahm et al., 2008).

The digestibility of amino acids in HP-DDG is within the range of values measured for DDGS, but data for only one source are available (Widmer, McGinnis, and Stein, 2007). However, the digestibility of amino acids in corn germ is less than in DDG and DDGS. The reason for this observation may be that the proteins in corn germ are different from other proteins in the grain kernel (Widmer, McGinnis, and Stein, 2007).

Although sorghum has a lower digestibility of amino acids than corn (Pedersen, Boersma, and Stein, 2007b), sorghum DDGS have amino acid digestibilities that are within the range of values observed in corn DDGS (Urriola et al. 2007). However, amino acid digestibility data for only one source of sorghum DDGS have been reported. The digestibility of amino acids was measured in one source of de-oiled corn DDGS and all values were reported to be within the range of values reported for conventional corn DDGS (Jacela et al., 2007).

Digestibility of Phosphorus

Fermentation results in release of a portion of the phytate-bound phosphorus in corn, which in turn results in a greater digestibility of phosphorus in fermented feed ingredients than in corn (Table 4.3). The apparent total tract digestibility of phosphorus is therefore much greater in DDGS and HP-DDG than in corn, whereas the digestibility of phosphorus in corn germ is similar to that of corn (Stein, Pedersen, and Boersma, 2005; Pedersen, Boersma, and Stein, 2007a; Widmer, McGinnis, and Stein, 2007). There are no data on the apparent total tract digestibility of phosphorus in other sources of distillers co-products produced from corn or in DDGS produced from sorghum.

Table 4.3. Concentration and digestibility of phosphorus in corn and distillers co-products produced from corn (as-fed basis)

Item	Corn	DDGS	HP-DDG	Corn Germ
N	2	10	1	1
Total phosphorus, %	0.22	0.61	0.37	1.09
Total phosphorus, % DM	0.25	0.70	0.40	1.18
Apparent total tract digestibility, %	24.1	59.0	59.6	28.6
Digestible phosphorus, %	0.05	0.36	0.22	0.31

Sources: Data from Bohlke, Thaler, and Stein, 2005; Pedersen, Boersma, and Stein, 2007a; and Widmer, McGinnis, and Stein, 2007.

Digestibility of Ether Extract

The apparent total tract digestibility of ether extract in DDGS has been reported in only one experiment that showed that the apparent total tract digestibility of ether extract in DDGS is approximately 70% (Stein, 2005). There is, however, a need for more information in this area, and several current research projects are directed at measuring both apparent and true digestibility of ether extract in DDGS and in other distillers co-products.

Digestibility of Energy

The apparent total tract digestibility of energy in most distillers co-products is lower than in corn because of the greater concentration of fiber in the co-products than in corn (Table 4.4). The fiber in DDGS has a low digestibility in the small intestine, and the fermentation in the large intestine is less than 50% complete, which is the reason for the low digestibility of energy in distillers co-products. In DDGS, the apparent total tract digestibility of energy is 82.9% compared with 90.4% in corn (Pedersen, Boersma, and Stein, 2007a). However, because of the larger oil concentration in DDGS compared to that in corn, the concentration of gross energy is also greater in DDGS than in corn (5,434 vs. 4,496 kcal gross energy/kg dry matter). The concentration of digestible energy in DDGS is, therefore, similar to that in corn (4,088 vs. 4,140 kcal digestible energy/kg dry matter; Stein, Pederson, and Boersma, 2005; Pedersen, Boersma, and Stein, 2007a). The concentration of digestible energy in corn germ (3,979 kcal digestible energy/kg dry matter) is also similar to that in corn, but HP-DDG have a greater concentration of digestible energy (4,763 kcal digestible energy/kg dry matter) than does corn (Widmer, McGinnis, and Stein, 2007). In contrast, de-oiled DDGS have a lower con-

Table 4.4. Concentration of energy in corn and in distillers co-products produced from corn and sorghum

Item	Corn	Corn DDGS	Sorghum DDGS	Corn HP-DDG	Corn Germ	De-oiled Corn DDGS
N	2	10	2	1	1	1
Gross energy, kcal/kg DM	4,458	5,434	4,908	5,399	5,335	4,655
Apparent total tract digestibility, %	90.0	76.8	76.0	88.2	74.6	-
Digestible energy, kcal/kg DM	4,072	4,140	3,459	4,763	3,979	3,093
Metabolizable energy, kcal/kg DM	3,981	3,897	-	4,476	3,866	2,851

Sources: Data from Feoli et al., 2007; Jacela et al., 2007; Pedersen, Boersma, and Stein, 2007a; and Widmer, McGinnis, and Stein, 2007.

centration of digestible energy than does corn (3,093 kcal digestible energy/kg dry matter; Jacela et al., 2007). The concentration of digestible energy in sorghum DDGS was measured in one experiment and reported to be approximately 220 kcal/kg (as-is basis) less than that in corn DDGS (Feoli et al., 2007), which may be the result of a lower concentration of ether extract in sorghum DDGS compared with that in corn DDGS.

Feeding Distillers Co-products to Swine

Inclusion of Distillers Co-products in Diets Fed to Sows

There are no negative effects of feeding diets containing up to 50% DDGS to gestating sows (Wilson et al., 2003), but the effects of feeding other distillers co-products to gestating sows have not been reported. Lactation feed intake, litter weight gain, and sows returning to estrus were not influenced by the inclusion of DDGS in diets (Wilson et al., 2003). However, sows fed DDGS in gestation and lactation for two consecutive parities had greater litter sizes in the second parity than sows fed a control corn-soybean-meal diet. The reason for this is unknown, but it may be a consequence of the increased fiber concentration in diets containing DDGS because litter size is sometimes improved if sows are fed high-fiber diets during gestation (Ewan et al., 1996; Grieshop, Reese, and Fahey, 2001). More research needs to be conducted to verify if the increase in litter size is a common consequence of including DDGS in diets fed to gestating sows.

Results of five experiments in which DDGS were fed to lactating sows have been reported, but there are no data on the inclusion of other distillers co-products. Inclusion rates of DDGS in these experiments were up to 15% (Hill et al., 2008b); 20% (Wilson et al., 2003), or 30% (Song et al., 2007a; Greiner et al., 2008) of the diet. Negative effects of including DDGS in diets fed to lactating sows were not observed in any of these experiments. There was no influence of DDGS on milk composition, apparent nitrogen digestibility, or nitrogen retention. However, sows fed diets containing 20% or 30% DDGS had lower values for blood urea nitrogen than sows fed the control diet (Song et al., 2007b), which indicates that these sows were fed diets with a better amino acid balance compared with sows fed the control diet. One experiment (Greiner et al., 2008) also showed that sows fed diets containing DDGS had improved weight gain in lactation and reduced wean-to-estrus intervals, but these effects were not reported in the other experiments. There is, however, no information on the performance of pigs farrowed by sows fed DDGS, but there are no indications that the growth performance of these pigs is influenced by the inclusion of DDGS in sow diets.

It is concluded that DDGS can be included in diets fed to gestating sows in concentrations of up to 50% and in diets fed to lactating sows in concentrations of up to 30% if diets are formulated based on concentrations of digestible energy, amino acids, and phosphorus. It is possible that the inclusion rate in diets fed to lactating sows can be greater than 30%, but no research has been conducted to verify this hypothesis.

Inclusion of Distillers Co-products in Diets Fed to Weanling Pigs

Effects of including DDGS in diets fed to weanling pigs have been investigated in eight experiments. Up to 30% DDGS can be used without negatively affecting performance if these diets are introduced two to three weeks post-weaning (Gaines et al., 2006; Spencer et al., 2007; Burkey et al., 2008). If DDGS-containing diets are fed to weanling pigs during the initial two weeks post-weaning, up to 25% DDGS may be included (Whitney and Shurson, 2004), and 7.5% DDGS may be included in diets from the day of weaning (Spencer et al., 2007). Improved feed conversion rates from DDGS inclusion have been reported in a few experiments (Gaines et al., 2006; Spencer et al., 2007), but this effect was not observed in other experiments.

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 pig performance (Feoli et al., 2008). It is likely that differences in the quality of sorghum DDGS used in these experiments are responsible for the different observations, but with the limited data that are available for sorghum DDGS, it is recommended that no more than 20% sorghum DDGS be used in diets fed to weanling pigs.

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

Inclusion of Distillers Co-products in Diets Fed to Growing-Finishing Pigs

Effects of distillers co-products on live pig performance. Results of 25 experiments in which DDGS were included in diets fed to growing-finishing pigs have been reported. No change in performance was observed in most of the experiments, but there are also examples of experiments in which a reduced performance was obtained when corn DDGS were included in the diet.

Up to 30% DDGS can be included in diets fed to growing-finishing pigs without negatively affecting pig performance (Cook, Paton, and Gibson, 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). However, data from other experiments in which 10%, 20%, or 30% DDGS were 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). In some of these experiments, the reduced growth performance could be an effect of reduced feed intake (Fu et al., 2004; Linneen et al., 2008), but that was not the case in other experiments (Whitney et al., 2006; Weimer et al., 2008). The reduced feed intake of diets containing DDGS may be related to reduced palatability of such diets compared with corn-soybean-meal diets (Hastad et al., 2005). It is also possible that the quality of DDGS that was used may have varied among experiments, which could have influenced the results. If, for example, DDGS with a low digestibility of lysine were used, pig performance would be expected to be reduced because lysine might then limit protein deposition. In addition, diets in some of the experiments in which poor pig performance was observed were formulated in such a way that the total crude protein concentration in the diet increased with the inclusion of DDGS. Increased dietary crude protein may result in poor pig performance, so in such diets, it is not possible to determine if the reduction in pig performance was a result of the DDGS in the diet or the increased crude protein content. However, DDGS-containing diets can be formulated without increasing dietary crude protein concentrations if crystalline lysine is used. Therefore, 0.10% lysine is included for each 10% DDGS in DDGS-containing diets (Stein, 2007). If more than 20% DDGS is used, it may also be necessary to include crystalline tryptophan in the diet (Stein, 2007).

There are eight reports on feeding sorghum DDGS to growing-finishing pigs, with results showing that 30% sorghum DDGS can be included in diets fed to growing-finishing pigs without reducing average daily weight gain, average daily feed intake, or the gain-to-feed ratio (Senne et al., 1996). However, if greater inclusion rates are used, pig performance will be reduced (Senne et al., 1996; Feoli et al., 2008). Based on these observations, it appears that growing-finishing pigs tolerate sorghum DDGS as well as corn DDGS.

Inclusion of corn HP-DDG in diets fed to growing-finishing pigs was reported in one experiment (Widmer et al., 2008). In this experiment, 40%, 30%, and 20% HP-DDG, respectively, were included in diets fed to pigs in the growing (22 to 60 kg), early finishing (60 to 95 kg), and late finishing (95 to 125 kg) stages. At these inclusion rates, HP-DDG replaced all the soybean meal in the corn-based diets, and the overall growth performance was not different for pigs fed the HP-DDG-containing diets compared with pigs fed the corn-soybean-meal control diet. However, in the growing phase, in which 40% HP-DDG was used, reduced feed intake and growth performance was observed for pigs fed the HP-DDG diet, but that was not the case during the later stages of growth or for the overall growing-finishing period (Widmer et al., 2008). It was concluded that HP-DDG may be included in corn-based diets fed to growing-finishing pigs at levels needed to replace all the soybean meal. It is, however, necessary to include relatively large concentrations of crystalline amino acids in diets containing HP-DDG to compensate for the low concentrations of lysine and tryptophan in this ingredient, and diets should always be formulated based on standardized ileal digestible amino acids.

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 distillers co-products, 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 for pigs fed diets containing corn germ. The researchers 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 has yet to be conducted. There have been no reports of experiments in which other distillers co-products were fed to growing-finishing pigs.

Effects of distillers co-products on carcass composition and quality. A reduced dressing percentage of pigs fed DDGS-containing diets has been reported in some of the experiments in which DDGS were fed to growing-finishing pigs (Cook, Paton, and Gibson, 2005; Whitney et al., 2006; Feoli et al., 2007; Gaines et al., 2007 a,b; Hinson et al., 2007; Xu et al., 2007a; Linneen et al., 2008; Weimer et al., 2008). It is possible that this is a consequence of the increased fiber concentration in DDGS-containing diets, because increased concentrations of dietary fiber have been reported to increase the mass of the intestinal tissue and the weight of the digesta (Kass, van Soest, and Pond, 1980). It is also possible that the aforementioned increase in crude protein in DDGS-containing diets may increase the weight of the intestinal tissue, which can also contribute to a reduction in dressing percentage (Ssu, Brumm, and Miller, 2004). However, the dressing percentage of pigs fed DDGS-containing diets is not always reduced, and in approximately 50% of the experiments in which dressing percentage was measured, no difference was observed (Fu et al., 2004;

Xu et al., 2007b; McEwen, 2006, 2008; Drescher et al., 2008; Hill et al., 2008a; Stender and Honeyman, 2008; Widmer et al., 2008). For pigs fed sorghum DDGS, dressing percentages have been reported to be either improved, reduced, or not changed (Senne et al., 1996, 1998; Feoli et al., 2007). It is not known why the dressing percentage for pigs fed DDGS-containing diets is sometimes reduced, whereas this is not the case in other experiments. The quality of the DDGS and the techniques used in diet formulation may contribute to these differences, but research to elucidate these variables is needed.

Backfat thickness, lean meat percentage, and loin depth are not influenced by the inclusion of corn DDGS in the diets, but belly thickness has been reported to decrease in some, but not all, experiments in which corn or sorghum DDGS were included in the diet. However, a reduction in belly firmness (Whitney et al., 2006; Xu et al., 2007a; Widmer et al., 2008) and an increase in the iodine values of carcass fat (Whitney et al., 2006; White et al., 2007; Xu et al., 2008; Hill et al., 2008a) were reported as a result of including corn DDGS in the diets. This increase is probably a consequence of the large quantities of unsaturated lipids that are present in corn DDGS because dietary lipids often are incorporated into carcass fat without hydrogenation. The increased incorporation of unsaturated fatty acids will reduce the firmness of the fat and increase the iodine values. However, inclusion of 1% conjugated linoleic acid in DDGS-containing diets during the final ten days before harvest may reduce iodine values and could be used to avoid the problem with soft fat in pigs fed DDGS (White et al., 2007). Alternatively, if DDGS are removed from the diets during the final three to four weeks prior to harvest, acceptable iodine values are observed in pigs fed diets containing DDGS during the earlier stages of growth (Hill et al., 2008a; Xu et al., 2008).

Pigs fed diets containing HP-DDG may also have softer bellies and increased iodine values compared with pigs fed corn-soybean-meal diets (Widmer et al., 2008). However, pigs fed diets containing corn germ have firmer bellies and reduced iodine values (Widmer et al., 2008). There are no reports of the effects of other distillers co-products on carcass composition and quality. The palatability of pork from pigs fed DDGS, HP-DDG, and corn germ was measured in one experiment (Widmer et al., 2008). Results reported that the overall acceptance of pork from pigs fed diets containing distillers co-products 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 comes from a pig that was fed distillers co-products.

Conclusions

The digestibility of nutrients in distillers co-products varies among sources. The variability is of the same magnitude as for other co-products. Heat damage to lysine often occurs, which results in a greater variation in the concentration of total and digestible lysine than for all other nutrients. It is therefore important that the concentration of lysine be measured before distillers co-products are included in diets fed to pigs. For corn DDGS, the average concentration of total lysine is approximately 0.78% and sources of DDGS with below-average concentrations of lysine also have concentrations of digestible lysine that are below average. Such qualities of DDGS should not be used in diets fed to pigs without extra fortification with crystalline lysine.

The inclusion of inorganic sources of phosphorus can be reduced in diets containing DDGS because the digestibility of phosphorus is greater in all fermented distillers co-products than it is in corn, but this is not the case for unfermented co-products. The concentration of starch is low in all distillers co-products and the concentration of fiber is relatively high in most co-products. The concentration of energy in the products is less variable than the digestibility of nutrients, but there is variation among the different co-products according to the procedure used to produce them.

If DDGS of average or above-average quality are used, approximately 30% can be included in diets fed to lactating sows, weanling pigs, and growing-finishing pigs, whereas 50% can be included in diets fed to gestating sows. Inclusion of sorghum DDGS should be limited to 20% in weanling pig diets, but 30% may be included in diets fed to growing-finishing pigs. Corn HP-DDG may be included in diets fed to growing-finishing pigs in quantities sufficient to substitute for all soybean meal, but there are no data on the inclusion of corn HP-DDG in diets fed to sows or weanling pigs. Corn germ can be included in diets fed to growing-finishing pigs in concentrations of at least 10%.

Carcass composition and palatability are not influenced by the inclusion of DDGS, HP-DDG, or corn germ in diets fed to growing-finishing pigs. However, belly firmness is reduced and fat iodine values are increased by the inclusion of DDGS and HP-DDG in these diets. It may therefore be necessary to reduce the inclusion of these products in diets fed during the final three to four weeks prior to slaughter.

All diets containing distillers co-products should be formulated in such a way that the concentration of crude protein is not greater than in traditional corn-soybean-meal diets. This requires the use of crystalline sources of amino acids to balance the amino acid profile of the diets.

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