SWINE FOCUS #001

Distillers dried grains with solubles (DDGS) in diets fed to swine

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Summary

Distillers dried grains with solubles (DDGS) is produced from the fuel ethanol industry and is available for inclusion in diets fed to swine. During recent years, several research projects have been completed to investigate the feeding value of DDGS. Crude nutrient concentrations, energy and nutrient digestibility values, and effects of including DDGS in diets fed to different categories of swine have been investigated.

The concentration of energy in DDGS is greater than in corn, but because of a lower digestibility of energy in DDGS than in corn, there is no difference in the concentration of digestible and metabolizable energy between DDGS and corn. The apparent and standardized ileal digestibility of amino acids in DDGS does vary among sources but, with the exception of lysine, the variability is no greater than what has been reported for other feed ingredients. Lysine in DDGS may be damaged if excessive heating is used during the drying process, which in turn leads to a low digestibility of lysine. To exclude heat damaged products from swine feeding, it is recommended that producers calculate the lysine to crude protein ratio and only use DDGS if this ratio is greater than 2.80%. The digestibility of phosphorus in DDGS is approximately 59%. This value is greater than in corn. Therefore, if DDGS is included in the diet, less inorganic phosphorus is needed and less phosphorus will be excreted in the manure.

Diets formulated to contain DDGS should be formulated on the basis of digestible amino acids and digestible phosphorus. In general, 10% DDGS can replace approximately 4.25% soybean meal and 5.70% corn, if 0.10% crystalline lysine is included in the diet. DDGS can be included in diets fed to nursery pigs, growing finishing pigs, and sows in amounts of 20% and in diets for gestating sows at 40%. At these inclusion rates, excellent performance of pigs has been reported provided that diets were formulated on the basis of digestible amino acids. Greater inclusion rates are possible, but may not always maximize pig performance.

Concentration and digestibility of energy and nutrients in DDGS

In the United States, most ethanol is produced from corn, but sorghum and barley are used at a few plants and some plants use blends of different cereal grains. The DDGS that is produced is characterized by the grain that was used to produce the ethanol, but even if the same grain is used, variability in the chemical composition of DDGS may be observed. Analyzed concentrations of energy and nutrients in a large number of DDGS samples are presented in Tables 1, 2, 3, and 4 along with measured contents of digestible energy, digestible phosphorus, and digestible amino acids.

The average concentration of gross energy in DDGS is approximately 5,530 kcal GE per kg dry matter (**DM**) or 2,514 kcal per lb of DM. This value is greater than the energy concentration in corn. However, the digestibility of energy in DDGS is lower than in corn and the measured concentration of digestible (**DE**) and metabolizable (**ME**) energy in DDGS is 4,140 and 3,897 kcal per kg DM, respectively (Pedersen et al., 2007). These values correspond to 1,882 and 1,771 kcal per lb DM and are not different from the DE and ME in corn (Table 1).

Because starch is converted to ethanol during the fermentation process, only small amounts of starch are present in DDGS (Table 2). However, the fiber in corn is not converted to ethanol so the concentration of fiber (i.e., ADF and NDF) is relatively high in DDGS (Table 2).

The phosphorus concentration in DDGS is approximately 0.60%. The apparent total tract digestibility of phosphorus in DDGS is approximately 59% (Table 3). The corresponding value for corn is 21.5%, which is significantly lower than in DDGS (Pedersen et al., 2007). The reason for the greater digestibility of phosphorus in DDGS than in corn may be that some of the bonds that bind phosphorus to the phytate complex in corn have been hydrolyzed during the fermentation process in the ethanol plants, which makes more phosphorus available for absorption. As a consequence, if DDGS is included in diets fed to swine, the utilization of organic phosphorus will increase and the need for supplemental inorganic phosphorus (i.e., dicalcium phosphate or monocalcium phosphate) will be reduced. This will not only reduce diet costs but also reduce the quantities of phosphorus that are excreted into the manure from the animals.

The concentration and standardized ileal digestibility of amino acids were determined in 36 samples of DDGS originating from 35 different ethanol plants in the Midwest (Table 4). The results showed that some variations exist for amino acid digestibility among different samples of DDGS (Stein et al., 2005; Pahm et al., 2006a and b; Stein et al., 2007; Urriola et al., 2007). This is true in particular for lysine that is more variable than all other indispensable amino acids in terms of digestibility (Fastinger and Mahan, 2006; Stein et al., 2006). The reason for this variation is believed to be that lysine may have been heat-damaged in some of the samples of DDGS, which has lowered the digestibility of lysine in these samples (Cromwell et al. 1993). Most amino acids in DDGS have a medium digestibility and, except for

Table 1. Concentration of energy in corn and 10 samples of distillers dried grains with solubles (DDGS) fed to growing pigs [a, b, c]

Item	Ingredient: Corn	DDGS Average	DDGS Standard dev. (SD)	DDGS Lowest value	DDGS Highest value
Gross energy, kcal/kg DM	4,496	5,434	292	5,272	5,592
Apparent total tract digestibility, %	90.4	76.8	2.73	73.9	82.8
Digestible energy, kcal/kg DM	4,088	4,140	205	3,947	4,593
Metabolizable energy, kcal/kg DM	3,989	3,897	210	3,674	4,336

[a] Data from Pedersen et al., 2007.
[b] All data are based on 11 observations per treatment.
[c] One kg = 1,000 g = 2.2 lb.

Table 2. Concentration of carbohydrates in 46 samples of distillers dried grains with solubles[a]

Item	Average	Low	High	SD
Starch, total, %	7.3	3.8	11.4	1.4
Starch, soluble, %	2.6	0.5	5.0	1.2
Starch, insoluble, %	4.7	2.0	7.6	1.5
ADF, %	9.9	7.2	17.3	1.2
NDF, %	25.3	20.1	32.9	4.8

[a] Unpublished data from the University of Illinois.

lysine, the variability among different samples is within the normal range of variation found in other feed ingredients. To reduce the risk of utilizing sources of DDGS that have a low digestibility of Lysine because of heat damage, the lysine to crude protein ratio can be calculated (Table 5). The low digestibility of lysine is often associated with a low analyzed concentration of lysine in the sample, which is the reason why the lysine to crude protein ratio gives an estimate of the quality of the lysine in the sample. If the lysine to crude protein ratio is 2.80% or greater, then the DDGS has an average or above average quality, but if the ratio is lower than 2.80, then the product has a reduced quality. Because lysine is usually the first limiting amino acid in diets fed to swine, DDGS samples with a lysine to crude protein ratio that is less than 2.80 should not be used.

Considerations when buying DDGS

Because there is some variability among sources of DDGS, it is recommended that producers examine concentrations of nutrients in the product before buying DDGS. To confirm that the product is a true DDGS product that has not been diluted with soy hulls or reduced in fat concentration, it is recommended that guarantees for nutrient concentrations are obtained from the supplier. The crude protein concentration should be at least 27% and total fat and total phosphorus concentrations should be at least 9 and 0.55%, respectively (Table 6). Concentrations of ADF and NDF should not exceed 12 and 40%, respectively. To avoid sources of DDGS that have been heat damaged, the lysine to crude protein ratio should be at least 2.80%. It is also recommended that producers seek assurances for the absence of mycotoxins in DDGS before it is purchased.

Formulating diets using DDGS

When formulating diets with DDGS, it is recommended that energy values that are similar to corn are used for DDGS. Diets should be formulated based on standardized ileal digestible amino acids and digestible phosphorus. Because the protein in DDGS is relatively low in lysine, additional crystalline L-lysine needs to be included in the diet when DDGS is used. In diets formulated for nursery pigs, growing finishing pigs, and lactating sows, the inclusion of crystalline L-lysine should be increased by 0.10% for each 10% DDGS that is included in the diet. At the same time, 4.25% more than 20% DDGS is included in the diet, 0.015% of crystalline L-tryptophan also needs to be added to the diet for each additional 10% DDGS that is being used.

Diet formulation

- Use same DE value for DDGS as for corn.
- Formulate diets based on standardized ileal digestible amino acids (check diet concentrations of digestible lysine and digestible tryptophan).
- Formulate diets based on digestible P.
- Only use DDGS if Lysine:CP ratio is greater than 2.80%.
- Decide on maximum inclusion level.

If diets for gestating sows are formulated with DDGS, less soybean meal can be removed from the diet because gestating sows have a relatively greater requirement for digestible tryptophan than lactating sows and growing pigs. Because DDGS has a low concentration of tryptophan, it is possible to maintain a proper tryptophan concentration in gestation diets only if the reduction in soybean meal is limited to 2.40% for each 10% DDGS that is included

Table 3. Concentration and digestibility of phosphorus (P) in 10 sources of distillers dried grains with solubles fed to growing pigs[a, b]

Item	Average	Low	High	SD
Total P, %	0.61	0.51	0.74	0.09
Total P, % DM	0.70	0.57	0.85	0.10
Apparent total tract digestibility, %	59	50	68	5.17
Digestible P, %	0.36	0.28	0.47	0.06

[a] Data from Pedersen et al., 2007.
[b] Data are based on 11 observations per treatment.

soybean meal and 5.70% corn can be removed (Table 7). Because of the greater concentration and digestibility of phosphorus in DDGS than in corn and soybean meal, 0.20% monocalcium phosphate can also be removed from the diet for each 10% DDGS that is used, but additional limestone is needed to maintain a proper concentration of calcium. If in the diet. As a consequence, if 10% DDGS is included in gestating diets, the concentration of corn in the diet can be reduced by 7.40% (Table 7).

Inclusion rates of DDGS in diets fed to swine

The inclusion of 20 to 30% DDGS in diets fed to growing pigs has resulted in excellent pig performance

Table 4. Concentration and digestibility of crude protein and amino acids in 36 samples of distillers dried grains with solubles (DDGS) fed to growing pigs[a, b]

Item	Concentration in DDGS, %				Standardized ileal digestibility, %			
	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 amino acids								
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
Dispensable amino acids								
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

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

in many experiments (Whitney et al., 2004; DeDecker et al., 2005; Cook et al., 2005; Spencer et al., 2007; Table 8). However, reduced feed intake of diets containing DDGS, and therefore, also reduced pig performance has been reported from some experiments (Fu et al., 2004; Linneen et al., 2006; Whitney et al., 2006b). The reduced feed intake may have been related to the specific source of DDGS that was used in these experiments or caused by increased crude protein levels in the DDGS containing diets. It has been shown that sometimes pigs prefer to eat diets containing no DDGS rather than diets containing DDGS (Hastad et al., 2005). However, if an acceptable quality of DDGS is used and if diets are carefully formulated using the principles outlined above, producers will be able to use at least 20% DDGS in diets fed to nursery pigs from 2 weeks post-weaning and to growing and finishing pigs without experiencing any reduction in pig performance. Greater inclusion rates may be used if a good source of DDGS is available and some producers are successfully using 30 to 35% DDGS in diets fed to growing pigs.

> ...it is recommended that producers calculate the Lysine to crude protein ratio and only use DDGS if this ratio is greater than 2.80%.

Inclusion of up to 20% DDGS in lactation diets and up to 40% in gestation diets has also been reported to have no effect or a slightly positive effect on reproductive performance of sows (Monegue and Cromwell, 1995; Wilson et al., 2003; Hill et al., 2005). It is, therefore, recommended that DDGS can be included in diets fed

Table 5. Concentration, standardized ileal digestibility (SID), and ratio of lysine to crude protein in distillers dried grains with solubles[a, b]

Item	Average	Low	High
Crude protein, %	27.5	24.1	30.9
Lysine, %	0.78	0.54	0.99
SID Lysine, %	62.3	43.9	77.9
SID Lysine, g/kg	0.50	0.27	0.70
Lysine:CP, %	2.86	2.18	3.54

[a] Data calculated from Stein et al., 2005; Pahm et al., 2006a and b; Stein et al., 2006; Urriola et al., 2007.
[b] Data are based on in vivo measurement of standardized ileal digestibility of lysine and other amino acids in 36 samples of DDGS.

Table 6. Check list when buying DDGS

Item	Minimum	Maximum
Crude protein, %	27.0	-
Fat, %	9.0	-
Phosphorus, %	0.55	-
Lysine	2.80% of crude protein	-
ADF	-	12.0
NDF	-	40.0

to sows at these concentrations. An overview of current recommendations for the inclusion of DDGS in diets fed to swine is presented in Table 9.

Other consequences of using DDGS

The relatively high concentration of fat in DDGS may increase problems with feed bridging in bins and feeders (Table 10). In some cases, therefore, it may be necessary to modify storage and delivery systems if DDGS is used. Diets containing DDGS are also bulkier than diets without DDGS. As a rule of thumb, for each 10% DDGS that is included in the diet, the volume of the diet will increase by approximately 3% compared with a corn-soybean meal diet. This means that if a feed bin has the capacity to hold 8 ton of a corn-soybean meal diet that same bin will only be able to hold 7.6 ton of feed if 20% DDGS is included in the diet.

The fat in DDGS has a relatively high concentration of unsaturated fatty acids, which may cause increased belly softness of pigs fed diets containing DDGS (Whitney et al., 2006b). This may become a problem if the finishing diet contains more than 20% DDGS, but not all packers discount pigs with soft bellies. Presently, research is being conducted to investigate possibilities for preventing pork bellies from becoming softer if high concentrations of DDGS are used in the diets.

The inclusion of DDGS in diets fed to nursery and growing pigs may improve intestinal health and reduce problems with ileitis (Whitney et al., 2006a). Many producers, therefore, prefer to have 20% DDGS in all diets fed to these categories of pigs, but research to demonstrate the health benefits of using DDGS has been inconclusive. Increased litter sizes of sows fed diets containing DDGS has also been reported from one experiment, but more research in this area is needed to verify the positive effects of DDGS on litter size.

The environmental impact of including DDGS in diets fed to swine has not been researched. However, the greater digestibility of phosphorus in DDGS than in corn and soybean meal will reduce the need for adding inorganic phosphates

Table 7. Replacement value of 10% distillers dried grains with solubles (DDGS) in diets fed to growing and reproducing swine

Item	Diet: Gestation diets	All other diets[a]
Corn	↓ 7.40	↓ 5.70
Soybean meal, 48%	↓ 2.40	↓ 4.25
Monocalcium Phosphate, %	↓ 0.22	↓ 0.20
Fat	↓ 0.10	↓ 0.05
L-Lysine HCL	↑ 0.03	↑ 0.10
Limestone	↑ 0.09	↑ 0.10

[a] If more than 20% DDGS is used in these diets, 0.015% of crystalline L-tryptophan needs to be included in the diet for each additional 10% DDGS that is used. Alternatively, the additional inclusion of DDGS can substitute corn and soybean meal as shown for gestating sows.

Table 8. Effects of including up to 20% distillers dried grains with solubles (DDGS) in diets fed to growing-finishing pigs[a]

Item	DDGS			SEM[b]	P-Value	
	0%	10%	20%		Linear	Quadratic
Initial wt, lb[c]	48.6	48.0	48.5	0.48	0.82	0.40
Final wt, lb[c]	273.0	281.0	274.8	2.77	0.77	0.23
Average daily gain, lb[c]	1.96	2.05	1.98	0.02	0.76	0.22
Average daily feed intake, lb[c]	5.65	6.05	5.72	0.08	0.78	0.11
Feed conversion ratio, lb/lb[c]	2.86	2.94	2.86	0.01	0.94	0.32
Hot carcass wt, lb[c]	194.3	201.8	195.1	2.54	0.91	0.25
Dressing, %	71.1	71.8	71.0	0.48	0.85	0.23
Lean meat, %	51.30	50.15	51.17	1.20	0.92	0.31
Longissimus muscle area, inches[2,c]	7.22	6.97	6.92	2.48	0.51	0.79
Longissimus muscle depth, inches[c]	2.39	2.33	2.27	0.24	0.25	0.94
10th rib backfat, inches[c]	0.98	1.02	0.94	0.21	0.70	0.46
Longissimus muscle marbling	2.17	2.13	2.29	0.40	0.68	0.69
Longissimus muscle color score	3.38	3.17	3.25	0.24	0.65	0.54
Longissimus muscle, 24 h pH	5.35	5.37	5.43	0.06	0.09	0.65
48-h drip loss, %	4.04	4.28	3.89	0.51	0.84	0.61
7-d purge loss, %	3.22	3.29	3.23	0.44	0.99	0.88
Belly thickness, inches[c]	53.69	52.28	47.19	4.50	0.01	0.18
Adjusted belly firmness score, degrees	4.77	4.77	4.72	0.46	0.82	0.90
Iodine value of belly fat	69.77	69.82	72.04	1.25	0.22	0.49

[a] Data from Widmer et al., 2007 (unpublished).
[b] Standard error of the mean.
[c] One pound (lb) = 454g; one inch = 2.54 cm.

Table 9. Recommended and maximum inclusion rates of distillers dried grains with solubles (DDGS) in diets fed to different categories of swine

Category	Recommended [a]	Maximum [b]
Gestation	40	50
Lactation	20	?
Nursery, week 0-2	0	20
Nursery, after wk 2	20	30
Grower	20	35
Early finisher	20	35
Late finisher	20	20

[a] Recommended inclusion rates are based on a review of experiments in which DDGS was included in diets fed to swine.
[b] Maximum inclusion rates are the maximum concentrations of DDGS that have been successfully used under field conditions. These inclusion rates are not always based on experiments published in the peer reviewed literature and it may not be possible to successfully use these concentrations of DDGS under all circumstances.

to the diets and the excretion of phosphorus to the manure will be reduced as well. On the other hand, the concentration of nitrogen will increase slightly in diets containing DDGS, which will increase the excretion of DDGS in the manure from the pigs.

Issues to be aware of when buying DDGS and other ethanol co-products

- Some plants are skimming off fat before drying the DDGS. This gives final products with 4 to 6% fat rather than 10% fat. Lower energy value. Only buy if price is considerably reduced.
- A few plants add soy hulls to DDGS to improve flowability. Will reduce energy concentration and digestibility. Check fiber levels.
- Check quality control plans for mycotoxins.
- Some plants sell DDG rather than DDGS. Better product – less heat damage and higher AA digestibility.
- Some plants sell high protein DDG. Less fat and phosphorus, less fiber, high energy, high protein.
- Many other co-products are or will become available in the future (corn germ, corn germ meal, Glutenol, Energia, corn hulls, etc.).

Economics of using DDGS in diets fed to swine

Because DDGS replaces both corn and soybean meal in diets fed to pigs, the economic value of DDGS depends on the cost of corn and soybean meal. The maximum price that can be paid for DDGS without increasing diet costs with different costs of corn and soybean meal are

Table 10. Expected consequences of feeding distillers dried grains with solubles (DDGS) to pigs

Item	You can expect
Flowability	May become a problem in bins and feeders
Diet bulk	Will increase by approximately 3% for each 10% DDGS in diet
Feed intake	No effect if good quality DDGS is used
Daily live gain	No effect if good quality DDGS is used
Feed conversion	No effect if good quality DDGS is used
Dressing percentage	May be reduced by up to 0.5 percentage units for each 10% DDGS in diet
Belly softness	May become a problem if more than 20% DDGS in finishing diet
Intestinal health	Some evidence for improvement, more research needed
Litter size	May increase if DDGS included in gestating diets, more research needed
P excretion	Will be reduced if diet formulated correctly
N excretion	Will increase slightly if diet formulated correctly

presented in Table 11. With constant costs of soybean meal, the maximum price that can be paid for DDGS increases approximately $9-10 for each $0.50 per bushel the cost of corn is increased. Likewise, if the price of soybean meal is increased by $25 per ton, then the price of DDGS can be increased by $11-12 without increasing diet costs. Before including DDGS in diets fed to swine, producers are advised to make their own calculations based on local prices for corn, soybean meal, and DDGS.

Conclusions

The usage of DDGS in diets fed to swine is rapidly increasing. Many producers are including 20% DDGS in diets fed to all categories of swine. While this level of inclusion is generally recommended, some producers are successfully using greater inclusion rates and it is possible that up to 35% DDGS can be included in diets fed to nursery pigs and growing finishing pigs. However, because of the risk of producing pork with soft bellies, the inclusion of DDGS in finishing diets should be limited to 20% until more research has been conducted to investigate the effects of higher inclusion rates on belly firmness of pigs. Likewise, it is generally not recommended that DDGS is included in diets fed to nursery pigs during the initial 2 weeks post weaning, but some producers have successfully included up to 20% DDGS in these diets as well. Regardless of the category of pigs being fed and the inclusion level, it is important that diets containing DDGS be carefully formulated based on concentrations of digestible amino acids and digestible phosphorus. Sources of DDGS that have a lysine to crude protein ration that is lower than 2.80 should not be used in diets fed to swine.

Table 11. Maximum price ($/ton) that can be paid for distillers dried grains with solubles (DDGS) at different costs of corn and soybean meal (SBM) without increasing cost of complete diet [a, b]

	Corn, $/bushel			
Soybean meal (47.5%), $/ton	2.5	3.0	3.5	4.0
175	109	119	128	138
200	120	130	140	150
225	131	141	151	161

[a] For each combination of costs for corn and soybean meal, the price indicated for DDGS will result in identical diet costs for a corn-soybean meal and a corn-soybean meal-DDGS diet.
[b] One bushel of corn = 25.45 kg; one ton of soybean meal = 907 kg.

References

Cook, D., N. Paton, and M. Gibson. 2005. Effect of dietary level of distillers dried grains with solubles (DDGS) on growth performance, mortality, and carcass characteristics of grow-finish barrows and gilts. J. Anim. Sci. 83(Suppl. 1): 335 (Abstr.).

Cromwell, G. L., K. L. Herkelman, and T. S. Stahly. 1993. Physical, chemical, and nutritional characteristics of distillers dried grain with solubles fed to chicks and pigs. J. Anim. Sci. 71:679–686.

DeDecker, J. M., M. Ellis, B. F. Wolter, J. Spencer, D. M. Webel, C. R. Bertelsen, and B. A. Peterson. 2005. Effects of dietary level of distillers dried grains with solubles and fat on the growth performance of growing pigs. J. Anim. Sci. 83(Suppl. 2): 79 (Abstr.).

Fastinger, N. D., and D. C. Mahan. 2006. Determination of the ileal amino acid and energy digestibilities of corn distillers dried grains with solubles using grower-finisher pigs. J. Anim.Sci. 84:1722-1728.

Hastad, C. W., J. L. Nelssen, R. D. Goodband, M. D. Tokach, S. S. Dritz, J. M. DeRouchey, and N. Z. Frantz. 2005. Effect of dried distillers grains with solubles on feed preference in growing pigs. J. Anim. Sci. 83(Suppl. 2): 73 (Abstr.).

Hill, G. M., J. E. Link, M. J. Rincker, K. D. Roberson, D. L. Kirkpatrick, and M. L. Gibson. 2005. Corn distillers dried grains with solubles in sow lactation diets. J. Anim. Sci. 83(Suppl. 2):82 (Abstr.).

Linneen, S. K., M. D. Tokach, J. M. DeRouchy, R. D. Goodband, S. S. Dritz, J. L. Nelssen, R. O. Gottlob, and R. G. Main. 2006. Effects of dried distillers grain with solubles on growing-finishing pig performance. Kansas State University Swine Day Report. P. 103-110.

Monegue, H. J., and G. L. Cromwell. 1995. High dietary levels of corn byproducts for gestating sows. J. Anim. Sci. 73(Suppl. 1):86. (Abstr.).

Pahm, A. A., D. Hoehler, C. Pedersen, D. Simon, and H. H. Stein. 2006a. Amino acid digestibility and measurement of blocked lysine in five samples of distillers dried grains with solubles in growing pigs. J. Anim. Sci. 84(Suppl. 1):285 (Abstr.).

Pahm, A. A., C. Pedersen, and H. H. Stein. 2006b. Evaluation of reactive lysine (homoarginine) as an in vitro procedure to predict lysine digestibility of distillers dried grains with solubles by growing pigs. J. Anim. Sci. 84(Suppl. 2):121 (Abstr.).

Pedersen, C., M. G. Boersma, and H. H. Stein. 2007. Digestibility of energy and phosphorus in 10 samples of distillers dried grains with solubles fed to growing pigs. J. Anim. Sci. IN PRESS.

Spencer, J. D., G. I. Petersen, A. M. Gaines, and N. R. Augsburger. 2007. Evaluation of different strategies for supplementing distillers dried grains with solubles (DDGS) to nursery pig diets. J. Anim. Sci. 85(Suppl. 2):XX (Abstr.). IN PRESS.

Stein, H. H., C. Pedersen, and M. G. Boersma. 2005. Energy and nutrient digestibility in dried distillers grain with solubles. J. Anim. Sci. 83(Suppl. 2):79 (Abstr.).

Stein, H. H., C. Pedersen, M. L. Gibson, and M. G. Boersma. 2006. Amino acid and energy digestibility in ten samples of distillers dried grain with solubles by growing pigs. J. Anim. Sci. 84:853-860.

Urriola, P. E., D. Hoehler, C. Pedersen, H. H. Stein, L. J. Johnston, G. C. Shurson. 2007. Amino acid digestibility by growing pigs of distillers dried grain with solubles produced from corn, sorghum, or a corn-sorghum blend. J. Anim. Sci. 85(Suppl. 2):XX (Abstr.). IN PRESS.

Whitney, M. H., and G. C. Shurson. 2004. Growth performance of nursery pigs fed diets containing increasing levels of corn distillers dried grains with solubles originating from a modern Midwestern ethanol plant. J. Anim. Sci. 82:122-128.

Whitney, M. H., G. C. Shurson, and R. C. Guedes. 2006a. Effect of including distillers dried grains with solubles in the diet, with or without antimicrobial regimen, on the ability of growing pigs to resist a Lawsonia intracellularis challenge. J. Anim. Sci. 84:1870-1879.

Whitney, M. H., G. C. Shurson, L. J. Johnson, D. M. Wulf, and B. C. Shanks. 2006b. Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grain with solubles originating from a modern Midwestern ethanol plant. J. Anim. Sci. 84:3356-3363.

Wilson, J. A., M. H. Whitney, G. C. Shurson, and S. K. Baidoo. 2003. Effects of adding distillers dried grains with solubles (DDGS) to gestation and lactation diets on reproductive performance and nutrient balance in sows. J. Anim. Sci. 81(Suppl. 2):47(Abstr.).