The Value and Use of Distiller's Dried Grains with Solubles (DDGS) in Swine Diets

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What is DDGS?

Corn distiller's dried grains with solubles (DDGS) is a co-product from dry mill ethanol plants resulting from the fermentation of corn starch to produce fuel ethanol and carbon dioxide. Each bushel of corn (56 lbs) fermented in a dry mill ethanol plant will produce approximately 2.7 gallons of ethanol, 18 lbs of carbon dioxide, and 18 lbs of DDGS. Yellow dent corn is used to produce ethanol and DDGS because it is an excellent source of readily fermentable starch. Corn contains about 62% starch, 3.8% corn oil, 8.0% protein, and 11.2% fiber, and 15% moisture. Because most of the starch is converted to ethanol during fermentation, the resulting nutrient fractions (protein, oil, fiber) are 2 to 3 times more concentrated in DDGS compared to corn.

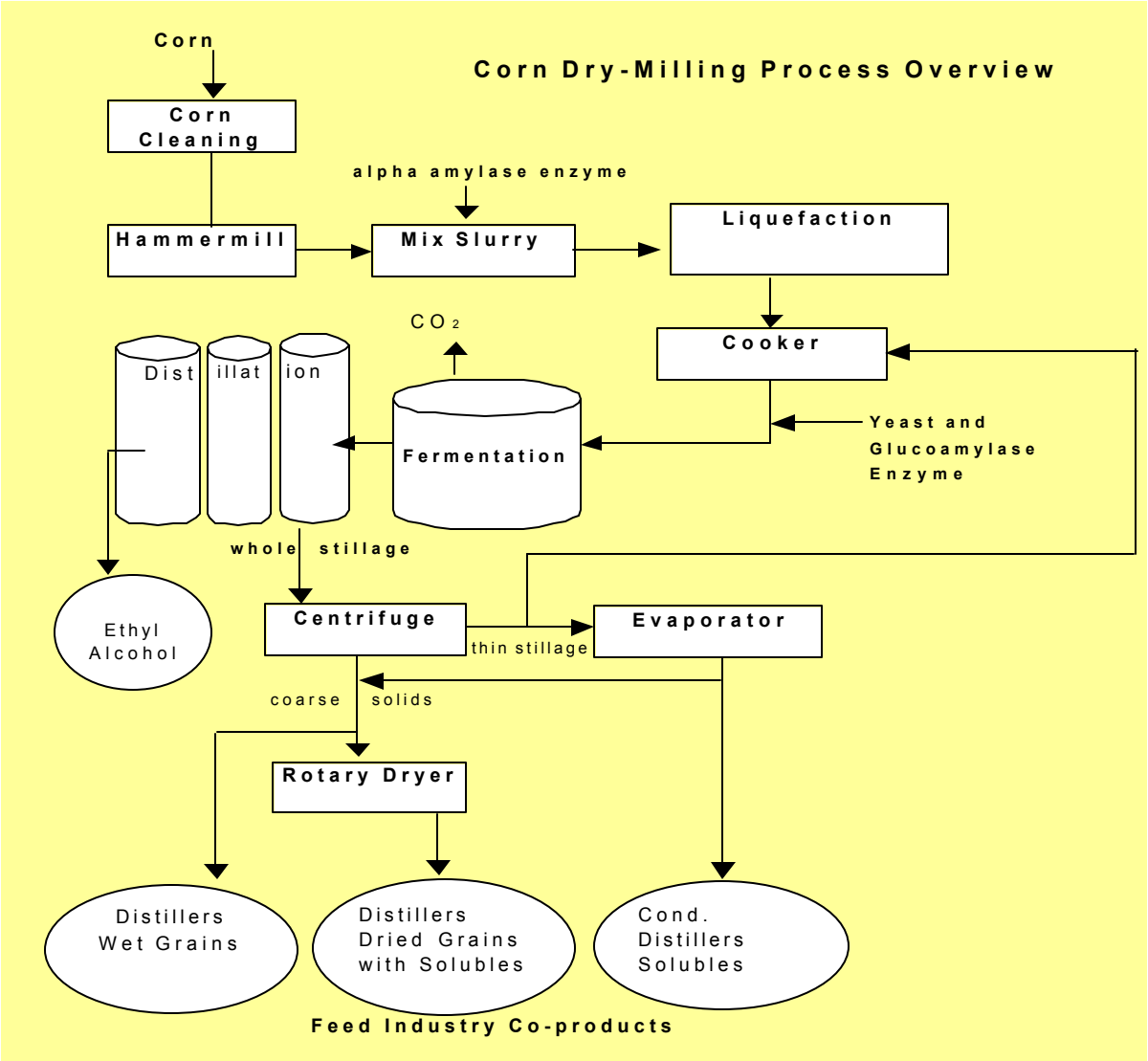
Why is There So Much Interest in Feeding DDGS to Swine?

One of the hottest topics in the feed industry today involves feeding "new generation" distiller's dried grains with solubles (DDGS) to swine. Historically, distiller's dried grains with solubles (DDGS) have not been used extensively in swine diets. The primary reasons for this limited use include variability in quality and nutrient content among sources, poor amino acid digestibility due to overheating during drying, concerns about the high fiber content, and cost competitiveness with corn, soybean meal and dicalcium phosphate. Although the majority (>80%) of DDGS has historically been fed to cattle, recent research studies conducted at the University of Minnesota have clearly shown that corn DDGS produced by "new generation" ethanol plants contains significantly higher levels of digestible and metabolizable energy, digestible amino acids, and available phosphorus than found in DDGS produced by older, more traditional ethanol plants. Because of its higher nutrient value, "new generation" DDGS is very well suited for swine and poultry diets, and can be a cost effective partial replacement for corn, soybean meal, and dicalcium phosphate in swine feeding programs.

As a result of recent research conducted at the University of Minnesota, usage of "new generation" DDGS in U.S. swine feeding programs has increased from about 30,000 tonnes in 2000 to more than 80,000 tonnes in 2002. The production of ethanol and DDGS is increasing at a rapid rate, which is due in part, to the banning of MTBE (methyl tertiary butyl ether) as an oxygenation agent in gasoline in 14 states, and the resulting increase in demand for ethanol to be used as a replacement for MTBE. Currently, the U.S. fuel ethanol industry produces about 3.8 million tonnes of DDGS. By 2005, this amount is projected to be near 5.5 million tonnes. New and undeveloped markets are needed to utilize this increased DDGS supply. The pork industry is a very viable, but underdeveloped DDGS market that could realize substantial economic benefits from using "new generation" DDGS.

How is DDGS Produced?

The dry milling ethanol production process involves grinding corn through a hammermill, adding yeast and enzymes to optimize ethanol production during fermentation, distilling the ethanol, and then centrifuging and drying the residual grains and solubles fractions by blending them before drying in a rotary or other type of dryer. Some ethanol plants have established a market for the wet grains and/or condensed solubles, which are fed wet to cattle. However, the quantity of wet co-products marketed by these plants is relatively low compared to the quantity of DDGS produced. The following figure provides a schematic view of the ethanol and DDGS production process (reproduced courtesy of Ms. Kelly Davis, Chippewa Valley Ethanol Cooperative, Benson, MN).



How Does the Nutrient Profile of DDGS Compare to Other Corn Co-Products?

There is considerable confusion among nutritionists and livestock producers regarding the nutritional similarities and differences among corn co-products. Approximately 40% of U.S. fuel ethanol is produced in dry mills, whereas the other 60% of ethanol production is produced in wet mills. Because the ethanol production processes are different between dry mills and wet mills, the resulting corn co-products are also nutritionally different. Dry mills produce DDGS, but wet mills produce corn gluten feed, corn gluten meal, and corn germ meal. According to Long (1985), wet milling of yellow dent corn involves its separation into the four major products (dry matter basis): corn starch (67.2 %), corn gluten feed (19.6 %), corn gluten meal (60% protein, 5.7 %), and corn germ (50% corn oil, 7.5 %).

The ethanol beverage industry also produces DDGS (< 1 % of total DDGS production), but is often dark in color, tends to be more variable in nutrient content (due to the type and source of grain used), and has lower levels of digestible nutrients than DDGS from "new generation" fuel ethanol plants. Brewer's dried grains are a co-product of the beer manufacturing industry and consist of the dried residue of barley malt and other grains that have been used to provide maltose and dextrins for fermenting. Use of brewer's dried grains in monogastric diets is limited due to the relatively high fiber level (18 to 19%).

Table 1. Nutrient Composition Comparison (As Fed Basis) between "New Generation" DDGS, Corn Gluten Feed, Corn Gluten Meal, Corn Germ Meal, and Brewer's Dried Grains (NRC, 1998).

	"New Generation" DDGS	Corn Gluten Feed NRC (1998)	Corn Gluten Meal NRC (1998)	Corn Germ Meal Feedstuffs (2001)	Brewer's Dried Grains NRC (1998)
Dry Matter, %	89	90	90	90	92
Crude Protein, %	27.2	21.5	60.2	20.0	26.5
Crude Fat, %	9.5	3.0	2.9	1.0	7.3
ADF, %	14.0	10.7	4.6	No data	21.9
NDF, %	38.8	33.3	8.7	No data	48.7
DE, kcal/kg	3529	2990	4225	No data	2100
ME, kcal/kg	3197	2605	3830	2900	1960
Arginine, %	1.06	1.04	1.93	1.3	1.53
Histidine, %	0.68	0.67	1.28	0.7	0.53
Isoleucine, %	1.01	0.66	2.48	0.7	1.02
Leucine, %	3.18	1.96	10.19	1.7	2.08
Lysine, %	0.74	0.63	1.02	0.9	1.08
Methionine, %	0.49	0.35	1.43	0.6	0.45
Cystine, %	0.52	0.46	1.09	0.4	0.49
Phenylalanine, %	1.32	0.76	3.84	0.9	1.22
Threonine, %	1.01	0.74	2.08	1.1	0.95
Tryptophan, %	0.21	0.07	0.31	0.2	0.26
Valine, %	1.34	1.01	2.79	1.2	1.26
Calcium, %	0.05	0.22	0.05	0.30	0.32
Phosphorus, %	0.79	0.83	0.44	0.50	0.56
Avail. Phosphorus, %	0.71	0.49	0.07	0.15	0.19

The primary nutritional advantages of "new generation" DDGS compared to corn gluten feed, corn gluten meal, and brewer's dried grains are the high levels of oil and available phosphorus (Table 1). The DE and ME value of "new generation" DDGS is significantly higher than corn gluten feed and brewer's dried grains, comparable to corn, but less than corn gluten meal. Amino acid levels of DDGS are lower than corn gluten meal and corn germ meal, but comparable to corn gluten feed and brewer's dried grains.

How is "New Generation" DDGS Different from "Old Generation" DDGS?

Research conducted at the University of Minnesota has shown that DDGS produced in "new generation", modern ethanol plants is higher in digestible and metabolizable energy, higher in digestible amino acids, and higher in available phosphorus than DDGS produced in older, more traditional ethanol plants. Although DDGS contains a significant amount of crude fiber, (7 to 8%), it also contains a high amount of crude fat (9 to 10% on an as fed basis) which results in DDGS containing an energy value (DE, 3965 kcal/kg; ME, 3592 kcal/kg) about equal to that found in corn (DE, 3961 kcal/kg; ME, 3843 kcal/kg) on a dry matter basis (Table 2).

Additional studies conducted at the University of Minnesota have shown that the "golden" colored DDGS produced in "new generation" ethanol plants contains significantly higher levels of amino acids (Table 3). Furthermore, the level of apparent digestible amino acids in "new generation" DDGS is higher than values from dark colored, "old generation" DDGS and values published in NRC (1998) shown in Table 4.

Perhaps the biggest nutritional advantage of feeding DDGS to swine is its high available phosphorus content. It is well know that corn is relatively low in phosphorus (0.28%), and relative phosphorus availability is also low (14%). However, the phosphorus content of "new generation" DDGS is 0.89% and the relative availability of phosphorus is increased to 90% after the corn has gone through the fermentation process (Table 5). With the eventual adoption of a phosphorus standard for livestock manure management plans, and the reduced need for supplemental inorganic phosphorus in DDGS supplemented swine diets, DDGS can reduce phosphorus excretion in manure as well as reduce diet cost due to less need for supplemental phosphorus in the diet.

Table 2. Comparison of Energy Values for DDGS (Dry Matter Basis).

	"New" DDGS Calculated	"New" DDGS Trial Avg.	"Old" DDGS Calculated	DDGS NRC (1998)
DE, kcal/kg	3965	4011	3874	3449
ME, kcal/kg	3592	3827	3521	3038

Corn: DE (kcal/kg) = 3961, ME (kcal/kg) = 3843.

Table 3. Comparison of Amino Acid Composition of DDGS (Dry Matter Basis) Between "New Generation" DDGS, "Old Generation" DDGS, and Values Published in NRC (1998).

	"New Generation" DDGS	"Old Generation" DDGS	DDGS NRC (1998)
Arginine, %	1.20 (9.1)	0.92 (18.7)	1.22
Histidine, %	0.76 (7.8)	0.61 (15.2)	0.74
Isoleucine, %	1.12 (8.7)	1.00 (9.1)	1.11
Leucine, %	3.55 (6.4)	2.97 (12.4)	2.76
Lysine, %	0.85 (17.3)	0.53 (26.5)	0.67
Methionine, %	0.55 (13.6)	0.50 (4.5)	0.54
Phenylalanine, %	1.47 (6.6)	1.27 (8.1)	1.44
Threonine, %	1.13 (6.4)	0.98 (7.3)	1.01
Tryptophan, %	0.25 (6.7)	0.19 (19.8)	0.27
Valine, %	1.50 (7.2)	1.39 (2.3)	1.40

Values in ( ) are coefficients of variation among ethanol plants.

Table 4. Comparison of Apparent Ileal Digestible Amino Acid Composition of DDGS (Dry Matter Basis) between "New Generation" DDGS, "Old Generation" DDGS, and Values Published in NRC (1998).

	"New Generation" DDGS	"Old Generation" DDGS	DDGS NRC (1998)
Arginine, %	0.90	0.60	0.88
Histidine, %	0.51	0.30	0.45
Isoleucine, %	0.72	0.42	0.73
Leucine, %	2.57	1.84	2.10
Lysine, %	0.44	0.00	0.31
Methionine, %	0.32	0.24	0.39
Phenylalanine, %	0.89	0.68	1.09
Threonine, %	0.62	0.36	0.56
Tryptophan, %	0.15	0.15	0.14
Valine, %	0.92	0.51	0.88

Values in ( ) are coefficients of variation among ethanol plants.

Table 5. Comparison of Phosphorus Level and Relative Availability of DDGS and Corn (dry matter basis).

	"New" DDGS	"Old" DDGS	DDGS NRC (1998)	Corn NRC (1998)
Total P, %	0.89	0.90	0.83	0.28
Relative P Availability, %	90	No data	77	14
Available P, %	0.80	No data	0.64	0.04

Can NIR Be Used Effectively to Measure Energy and Amino Acid Content in "New Generation" DDGS?

We conducted a collaborative study with Dr. Joe Hahn (Hubbard Milling, Mankato, MN) and Dr. Theo van Kempen (North Carolina State University) to determine the reliability of NIR calibrations for "new generation" DDGS. A total of 103 DDGS samples from 9 "new generation" ethanol plants were ground using a Retsch grinder through a 0.5 mm screen. Gross energy was determined for each sample using a bomb calorimeter. Amino acid values previously assayed at the University of Missouri were used in the calibration. Ground samples were analyzed with an NIR Systems model 6500 spectrophotometer using a half-sized rectangular cup. Scans were obtained from 400 to 2500 nm. Calibrations were developed using partial least squares regression with cross validation. Our results showed that calibrations for amino acids and energy in dried distiller's grain and solubles can be developed using NIRS. The quality of these calibrations is dependent on the calibration method used, with PLS1 calibrations preferred over PLS2 calibrations. Overall, the quality of these calibrations was reasonable (Table 6).

Table 6. NIR Calibration Results for "New Generation" DDGS.

Nutrient	R	Rmsep, %	R^2	CV, %
Lysine	0.89	0.064	.79	16.2
Methionine	0.81	0.044	.66	14.2
Threonine	0.73	0.046	.53	6.2
Energy	0.87	37	.76	1.9

R = correlation between actual and predicted values.
Rmsep = prediction error.
R^2 = proportion of the total variation explained by the calibrations.
CV, % = coefficient of variation among DDGS samples.

What Physical Characteristics are Important for Assessing DDGS Quality?

Color

Color appears to be the most important indicator of quality and nutrient digestibility of DDGS. A "golden colored" DDGS generally indicates higher amino acid digestibility compared to a dark colored DDGS. As shown in Table 4, apparent ileal digestibility of amino acids was lower for the darker colored, "old generation" DDGS compared to the golden colored, "new generation" DDGS fed to pigs in that amino acid digestibility study. Similarly, Cromwell et al. (1993) conducted a study to compare physical, chemical, and nutritional characteristics of nine different sources of DDGS for chicks and pigs. The color of these DDGS sources ranged from very light to very dark, and odor ranged from a sweet smell to smoky or burnt smell. Lysine concentration tended to be highest in light-colored DDGS and lowest in the darkest-colored DDGS sources. When the DDGS from the dark sources were added to diets and fed to chicks, growth rate, feed intake, and feed conversion were reduced 18 %, 13%, and 6 %, respectively, compared to chicks fed diets containing light-colored DDGS. Results from this study suggest

that DDGS that is dark in color and/or has a burned smell has a lower nutritional value in swine or poultry diets.

Smell

Golden colored, "new generation" DDGS also has a sweet, fermented smell unlike lower quality, dark colored DDGS that often has a burned or smoky smell. These differences in color and smell are largely due to types of dryers and drying temperatures used in various ethanol plants, but can also be influenced by the proportion of liquid solubles added to distiller's grains to produce DDGS.

Particle size

We have completed an evaluation of physical characteristics and chemical composition of DDGS among 16 ethanol plants in Minnesota, South Dakota, and Missouri. Table 7 shows a summary of the bulk density and particle size analysis results from this study. The average particle size among the 16 ethanol plants was 1282 microns (SD = 305, CV= 24%), and ranged from 612 microns in plant 6 to 2125 microns in plant 15. Thus, there is considerable variation in average particle size of DDGS originating from these "new generation" ethanol plants. DDGS produced by plants with high average particle size may require further grinding to improve particle size uniformity and optimize nutrient digestibility of DDGS in a complete mixed feed. Plant 15 had the highest mean particle size (2125 microns). Ethanol plants that produced DDGS with high amounts of "syrup balls" tended to have a higher mean particle size. There was similar distribution of particle size among all plants except plants 6 and 15.

Bulk density

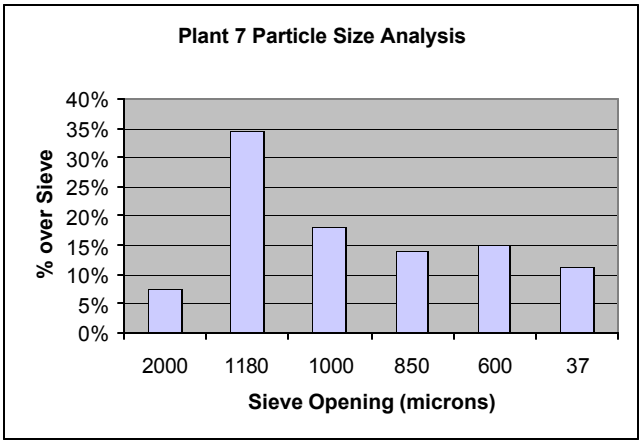
Bulk density averaged 35.7 lbs/cubic foot (SD = 2.79, CV = 7.8%), but ranged from 30.8 to 39.3 lbs/cubic foot. However, the correlation between mean particle size and bulk density was surprisingly very low (r= 0.05) which may be due to the variable amounts of "syrup balls" among the samples collected. Most samples had a "golden" color, but samples from plants 2, 8b, and 15 were darker than the other samples collected.

Variation in nutrient content

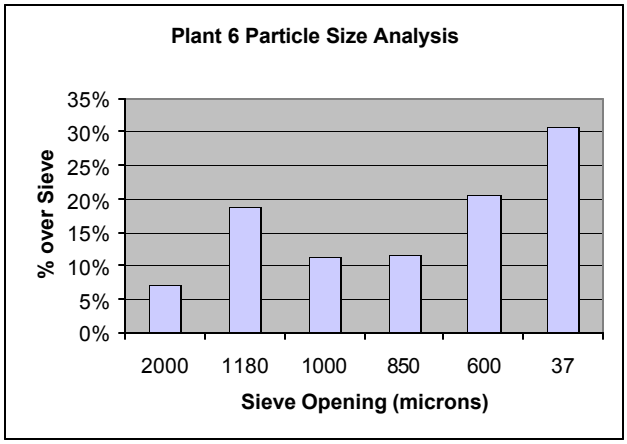
Chemical analysis of DDGS from each ethanol plant for moisture, crude protein, crude fat, and crude fiber are shown in Table 8. Average moisture content of DDGS was 11.69% (SD = 0.91, CV = 7.8%). Average crude protein, crude fat, and crude fiber of DDGS was 26.63% (SD = 0.97, CV = 3.63%), 10.06% (SD = 0.70, CV = 7.00%), and 6.9% (SD = 0.78, CV = 11.27%), respectively. Crude fiber content of DDGS was the most variable among ethanol plants, followed by moisture, crude fat, and crude protein content. The correlation between bulk density and moisture was r = –0.68, which means that there appears to be a moderate negative relationship between bulk density of DDGS and moisture content. In other words, as the moisture content of DDGS decreases, the bulk density tends to increase. However, unlike the moderate correlation between bulk density and moisture content, the correlations between bulk density and crude protein, crude fat and crude fiber were negative and relatively low (r = - 0.18, -

0.16, and – 0.20, respectively). This suggests that nutrient content (except moisture) has very little relationship with bulk density of DDGS.

Typical particle size distribution in new generation" DDGS



Particle size distribution for the low average particle size ethanol plant



Particle size distribution for the high average particle size ethanol plant

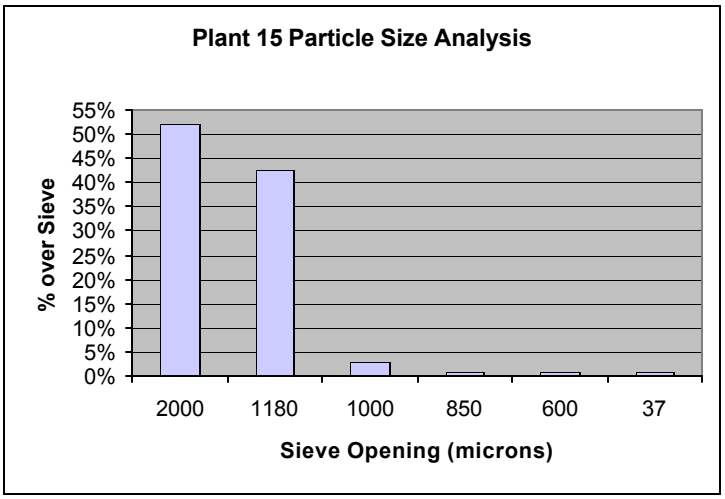


Table 7. Particle Size Mean and Variation Within "New Generation" Ethanol Plants and Bulk Density of DDGS.

	Particle Size Mean	Standard Deviation	Bulk Density	CV %	68% of the particles will fall between	
Plant 1	1398	2.32	36.3	0.17	603	3243
Plant 2	1322	2.00	39.2	0.15	661	2644
Plant 3	1425	1.62	36.8	0.11	880	2309
Plant 4	1370	1.84	36.3	0.13	745	2521
Plant 5	1255	1.68	33.5	0.13	747	2108
Plant 6	612	2.75	39.3	0.45	223	1683
Plant 7	974	2.15	36.1	0.22	453	2094
Plant 8a	1258	1.70	33.7	0.14	740	2139
Plant 8b	1142	1.84	30.8	0.16	621	2101
Plant 9	1337	1.78	31.8	0.13	751	2380
Plant 10	1488	1.62	38.2	0.11	919	2411
Plant 12	1235	1.75	31.4	0.14	706	2161
Plant 13	1198	1.87	35.9	0.16	641	2240
Plant 14	1229	2.09	39.2	0.17	588	2569
Plant 15	2125	1.56	37.6	0.07	1362	3315
Plant 16	1148	2.25	35.1	0.20	510	2583
Average	**1282.25**	**1.93**	**35.7**	**0.15**	**697**	**2406**

Table 8. Proximate Analysis of DDGS from "New Generation" Ethanol Plants in Minnesota, South Dakota, and Missouri.

Plant ID	Moisture, %	Crude Protein, %	Crude fat, %	Crude fiber, %
1	10.83	24.54	9.59	6.40
2	11.20	26.61	9.51	6.80
3	9.67	25.95	9.43	7.30
4	11.55	26.33	10.53	6.70
5	11.48	26.41	10.43	7.60
6	10.91	26.17	9.60	6.80
7	12.18	28.42	9.20	7.30
8a	11.83	27.36	9.27	6.80
8b	12.36	26.09	9.66	6.10
9	13.27	26.59	11.13	6.70
10	11.07	26.57	10.82	6.00
12	13.57	28.15	10.84	7.30
13	12.30	28.15	9.50	7.50
14	11.43	26.91	9.97	6.20
15	11.72	25.99	11.55	5.80
16	11.65	25.85	9.87	9.10
Avg.	11.69	26.63	10.06	6.90
Std. Dev. Among Plants	0.91	0.97	0.70	0.78
CV Among Plants	7.80	3.63	7.00	11.27

Minnesota Certified DDGS

In order to differentiate DDGS sources that are suitable for swine and poultry diets from lower quality sources, several Minnesota ethanol plants are in the process of implementing a Minnesota Certified DDGS program to provide DDGS customers with assurances (third-party certification from the Minnesota Department of Agriculture) that specific nutrient specifications, physical characteristics, and production processes are being met.

Proposed nutrient specifications

Moisture – maximum 12%
Crude protein – minimum 26.5%
Crude fat – minimum 10%
Crude fiber – maximum 7.5%

Proposed physical characteristics

Bulk density – 34 to 37 lb/cubic foot
Particle size:
maximum coarse particles - 10% on 2000 screen
maximum fine particles - 15% on 600 screen & in pan
Smell – fresh, fermented
Color – goldenrod

Are There Limitations on Using "New Generation" DDGS in Swine Diets?

DDGS, like every feed ingredient, has some nutritional characteristics that limit its use in swine diets. First, DDGS has a poor amino acid profile (as found in corn) relative the pig's amino acid requirements. The relatively high crude protein (nitrogen) content (30%) will result in increased manure nitrogen excretion when high levels of DDGS are fed. However, use of synthetic amino acids, formulating diets on a digestible amino acid basis, and limiting the use of DDGS to less than 20% of the diet will minimize excess nitrogen intake and excretion.

The high fiber content of DDGS limits its use in phase I diets for early weaned pigs but it supports excellent performance in phase II, and subsequent nursery and grow-finish diet phases. When high levels of DDGS are added to gestation (up to 50% DDGS) and lactation (up to 20% DDGS) diets, and sows are abruptly switched from a corn-soybean meal based diet to a high DDGS diet, feed intake is often reduced for a period of 5 to 7 days until sows become acclimated to high DDGS diets. This short-term, reduced feed intake response is commonly observed when sows are fed diets high in fiber. However, this effect can be eliminated by either using lower inclusion rates of DDGS (10%) in sow diets, or by gradually transitioning from low DDGS to high DDGS diets during each production phase.

The high oil content of DDGS may limit its maximum inclusion rate in grow-finish diets. Our studies have shown that when feeding DDGS to grow-finish pigs (50-250 lbs), pork carcass fat will become softer and more oily with increasing levels of DDGS in the diet. Similar effects have been shown when adding any high oil grain or grain co-product to swine grow-finish diets. Although softer fat and reduced belly firmness are a concern for packers and meat processors,

there are currently no price penalties for pork producers for marketing pigs with reduced pork fat quality. Results from our studies show that feeding up to 20% DDGS in grow-finish diets has no effect on belly thickness or belly firmness score compared to carcasses from grow-finish pigs fed conventional corn-soybean meal diets.

Like corn, DDGS can also pose a risk of introducing mycotoxins to the diet. If mycotoxin contaminated corn is used to produce ethanol and DDGS, the mycotoxin content of DDGS will be 2 to 3 times higher than the concentration found in the contaminated corn. This is because the removal of starch makes all other components of DDGS more concentrated, and mycotoxins resist degradation during the fermentation process. However, "new generation" ethanol plants located in the upper Midwest have lower risk of mycotoxin contamination due to cooler, less humid growing conditions, and the use of locally grown corn for the production of ethanol and DDGS. Despite the potential risk of mycotoxin contamination, it is extremely rare for DDGS to cause mycotoxicosis in swine feeds.

What Are the Recommended Dietary Inclusion Rates for "New Generation" DDGS?

Currently, most nutritionists in the feed and pork industry are using up to 5% in nursery pig diets (pigs weighing more than 15 lbs), up to 10% in grow-finish and lactation diets, and up to 20% in gestation diets. Adding "new generation" DDGS at these inclusion levels provides excellent performance and feed cost savings. Research results from the University of Minnesota have shown that "new generation" DDGS can be fed up to 25% in phase II and phase III nursery diets, up to 20% in grow-finish and lactation diets, and up to 50% in gestation diets and provide satisfactory performance. However, in order to achieve high performance at these high inclusion rates, the DDGS source and nutrient variability must be known, diets must be formulated on a digestible amino acid and available phosphorus basis, and DDGS must be free of mycotoxins.

How Should Swine Diets Containing "New Generation" DDGS be Formulated to Obtain Optimal Performance and Value?

Our research results have shown that energy and amino acid digestibility, as well as phosphorus availability of DDGS produced in Minnesota and South Dakota ethanol plants, is higher than almost all of the values reported in NRC (1998), as well as amino acid digestibility values we obtained from evaluating low quality DDGS (Table 1). Our apparent digestible amino acid and available phosphorus nutrient values should be used to formulate practical diets for all phases of production to ensure that the maximum nutritional value of DDGS is obtained, and that optimal performance is achieved, particularly when adding more than 10% DDGS to any swine diet. Formulating diets using total amino acid and phosphorus values may provide acceptable performance at low inclusion rates (< 10%) of DDGS in swine diets, but will not capture the full nutritional value of DDGS.

How Do I Determine if the Price of DDGS is Cost Competitive with Corn, Soybean Meal (46%) and Dicalcium Phosphate?

Assuming a 10% inclusion rate for DDGS in a growing swine diet, and formulating on an available phosphorus and apparent digestible amino acid basis, 100 kg of "new generation"

DDGS and 1.5 kg of limestone will replace 89 kg of corn, 9.5 kg of soybean meal (46%), and 3 kg of dicalcium phosphate. By knowing the current prices for each of these ingredients, simply calculate the value of each of these ingredients to determine an opportunity cost for DDGS as follows:

Additions/1000 kg diet			
+ 100 kg DDGS	x	cost/kg	= $
+ 1.5 kg limestone	x	cost/kg	= $
TOTAL ADDITIONS (A)			**= $**
Subtractions/1000 kg diet			
- 89 kg corn	x	cost/kg	= $
- 9.5 kg **SBM (46%)**	x	cost/kg	= $
- 3 kg dicalcium phosphate	x	cost/kg	= $
TOTAL SUBTRACTIONS (S)			**= $**

S - A = Opportunity cost for DDGS/100 kg

Does "New Generation" DDGS Provide Any Gut Health Benefits for Pigs?

There have been several field reports where pork producers have observed improvements in gut health in herds with recurring problems with ileitis (porcine proliferative enteropathy) when they have added 5 to 15% DDGS to finishing diets. Ileitis is caused by *Lawsonia intracellularis,* a microaerophil bacteria that infects immature epithelial cells located in the crypts of the small intestine. The organism inhibits the maturation of intestinal cells resulting in cells multiplying without being sloughed off. The result is a thickening of the intestinal wall and hemorrhaging.

We have conducted two disease challenge studies to evaluate the effects of feeding DDGS on reducing the negative consequences caused by an ileitis infection. The objectives of our first experiment were to: (1) develop a disease challenge model that can be utilized to evaluate nutritional effects on pig resistance to an ileitis challenge, (2) determine if dietary inclusion of DDGS affects the incidence or severity of ileitis in growing pigs, and (3) determine which dietary level of DDGS (10 or 20%) elicits the greatest response in the pig during an ileitis challenge.

In this study, we utilized 80 crossbred pigs (40 gilts, 40 barrows) that were weaned at 17 days of age, and were transported to the CVM-RAR isolation barns located on the University of Minnesota, St. Paul campus. Pigs were randomly allotted (blocked by sex and weight) to one of four treatments. Pigs were housed in separate rooms (10 pigs/room, 2 rooms/treatment). All pigs were fed a commercial Phase 1 pelleted diet during the first 4 days of the trial, and were subsequently placed on their respective experimental diets for the remainder of the study. Experimental diets were formulated to contain equivalent energy (3390 kcal/kg ME), calcium (0.80%), total phosphorus (0.70%), and apparent ileal digestible lysine (1.15%).

Treatment:	Diet:	Lawsonia Challenge:
(1) Negative Control (NC)	Corn-soybean meal	No
(2) Positive Control (PC)	Corn-soybean meal	Yes
(3) 10% DDGS (D10)	10% DDGS	Yes
(4) 20% DDGS (D20)	20% DDGS	Yes

Four weeks after experimental diets were initiated, pigs were provided 60 ml of either saline (NC) or an inoculation of *Lawsonia intracellularis* (PC, D10, and D20 treatments) via stomach tube. The inoculate was prepared as a mucosal homogenate collected from the small intestines of pigs previously infected with *Lawsonia intracellularis* and exhibiting lesions consistent with ileitis. Care was taken to avoid cross-contaminating pigs from different rooms. Growth and feed intake data were collected for the pre- and post-inoculation periods. Pigs were observed for gauntness and lethargy, and fecal scores indicating degree of firmness or looseness were taken. Fecal samples were collected on day 14 and 20 post-inoculation, and sent to the University of Minnesota Diagnostic Laboratory for PCR evaluation of *L. intracellularis* shedding. On day 20 or 21 post-inoculation, all pigs were euthanized and necropsies were performed to visually evaluate lesions, and to collect ileal tissue samples for immunohistochemistry (IHC) testing of *L. intracellularis* presence and proliferation.

Growth performance data were analyzed by room using analysis of variance, (two replications per treatment). All other data were analyzed utilizing individual pigs as the experimental unit, which provided 20 replications per treatment. Least squares means were used to compare data from the negative and positive control groups in order to evaluate the effects of infected pigs compared to non-infected pigs for the response criteria measured. Analysis of variance was conducted to compare response criteria among the disease challenge treatments (PC, D10, and D20). In addition, least squares means comparisons were conducted between challenged treatments to identify differences due to dietary DDGS inclusion level.

All pigs survived the disease challenge and remained on test for the duration of the experiment. Body weights, growth performance, feed intake, and feed efficiency results are shown in Table 9. Average initial pig weight was 5.7 kg at the beginning of the trial. During the pre-challenge period, feed intake and feed efficiency were similar across all treatments, although pigs fed the 10% DDGS diet tended to grow slightly faster than pigs fed the 20% DDGS diet. Infecting pigs with *L. intracellularis* greatly reduced feed intake, growth, and feed efficiency by 25, 55, and 40%, respectively, during the 3-week post-challenge period compared to uninfected pigs ($P < 0.01$). In addition, looser fecal consistency was observed (data not shown) from day 5 to day 20 post-challenge in challenged pigs compared to unchallenged pigs ($P < 0.10$). Dietary treatment (0, 10, or 20% DDGS) did not affect growth, feed intake, or feed conversion responses post-challenge, however, and resulted in similar end body weights.

Table 9. Effect of Adding 10 or 20% DDGS to Swine Diets on Gain, Feed Intake, and Feed Conversion of Growing Pigs Under an Ileitis Challenge.

	NC	PC	D10	D20
# pens/treatment	2	2	2	2
Initial body wt., kg	5.7	5.7	5.7	5.7
Challenge body wt., kg	16.7	17.5	17.8	16.9
Final body wt., kg	29.9	24.5	23.7	22.6
Pre-challenge (d 0 –32)				
ADG, g	354	379[a,b]	389[a]	360[b]
ADFI, g	567	595	593	589
G/F	0.62	0.64	0.66	0.61
Post-challenge (d 32 – 53)				
ADG, g	600	311	259	245
ADFI, g	1363	990	1012	1067
G/F	0.44	0.31	0.26	0.23

[a,b] Different superscripts between means within challenge treatments are different (P< .1).

Necropsy results are presented in Table 10. No lesions were observed for the negative control group. Overall, 63% percent of pigs that were challenged exhibited lesions consistent with ileitis. No dietary effects on total tract prevalence were observed, although pigs fed the 10% DDGS diet had more area (length) of lesions (P < .09) compared to challenged pigs (PC) fed the control diet, and pigs fed the 20% DDGS diet intermediate. These results are consistent with differences observed for jejunum lesion length. Pigs fed the 10% DDGS diet had more severe lesions (higher score) in the cecum and colon compared to pigs fed the 0% and 20% DDGS diets, indicating a higher level of infection. However, no dietary differences were noted in lesion length, severity, or prevalence in the ileum.

Laboratory results are presented in Table 11. The PCR technique for determining *L. intracellularis* presence in feces is currently the most precise technique for testing ileitis in the live pig. Four negative control (NC) pigs on day 14 post-challenge, and 8 NC pigs on day 20 post-challenge tested positive, indicating that some cross-contamination between rooms occurred after the disease challenge. By day 20 post-challenge, 80 to 100% of the inoculated pigs tested positive for shedding *Lawsonia*. A slightly higher percentage of pigs fed the DDGS diets tested positive (95 to 100%) compared to positive control pigs (80%).

Immunohistochemistry (IHC) results, however, indicated no difference in concentration or percentage of pigs testing positive for *L. intracellularis*. IHC is currently the most sensitive and accurate method of evaluating presence of ileitis, but requires submission of intestinal tissue for laboratory analysis, and therefore, involves sacrificing pigs. IHC results indicated that 30% of the NC pigs were exposed and were infected with ileitis, but that the disease was in an early stage of infection by the end of the study.

Table 10. Effect of Adding 10 or 20% DDGS to Swine Diets on Lesion Location, Length, Severity, and Prevalence in Growing Pigs Under an Ileitis Challenge.

	NC	PC	D10	D20
# pigs/treatment	20	20	20	20
Jejunum				
Length, cm	0.0	15[a]	54.4[b]	31.9[a,b]
Score (0-4)	0.0	0.4[a]	1.1[b]	1.2[b]
Prevalence, %	0.0	20.0[a]	50.0[b]	45.0[b]
Ileum				
Length, cm	0.0	7.5	11.8	11.1
Score (0-4)	0.0	0.9	1.5	1.5
Prevalence, %	0.0	50.0	65.0	60.0
Cecum				
Length, cm	0.0	0.0[a]	1.5[b]	0.15[a]
Score (0-4)	0.0	0.0[a]	0.5[b]	0.05[a]
Prevalence, %	0.0	0.0[a]	20.0[b]	5.0[a]
Colon				
Length, cm	0.0	1.0	6.2	0.6
Score (0-4)	0.0	0.3[a]	0.7[b]	0.2[a]
Prevalence, %	0.0	20.0	25.0	10.0
Total Tract				
Length, cm	0.0	23.4[a]	73.8[b]	43.7[a,b]
Prevalence, %	0.0	55.0	70.0	65.0

[a,b] Different superscripts between means within challenge treatments are different (P< .1).

Table 11. Effect of Adding 10% or 20% DDGS to Swine Diets on Fecal PCR and Ileal Tissue IHC Scores in Growing Pigs Under an Ileitis Challenge.

	NC	PC	D10	D20
# pigs/treatment	20	20	20	20
Fecal PCR				
Day 0	0.0	0.0	0.0	0.0
Day 14	20.0	70.0[a]	90.0[b]	90.0[b]
Day 20	40.0	80.0[a]	95.0[b]	100.0[b]
IHC				
Score (0-4)	0.55	2.00	2.15	2.25
Prevalence, %	30.0	100.0	90.0	95.0

[a,b] Different superscripts between means within challenge treatments are different (P< .1).

The target dose of *L. intracellularis* inoculation for this study was 1 x 10^8 per pig. Unfortunately, this target dosage was difficult to achieve because the inoculate is a mucosal homogenate that is harvested from infected tissues on the day of inoculating the pigs. Therefore, laboratory quantification of the actual concentration of *L. intracellularis* is not possible prior to the disease challenge. We later determined that the actual concentration of *L. intracellularis*

used was 2.6 x 10^7 per ml, or a dosage rate of 1.56 x 10^9 per pig. Since this dosage was much higher than our original goal, and visual observations during post-challenge and necropsy indicated that animals were more severely infected than normally be observed in the field, we believe that any possible nutritional benefits of feeding DDGS on controlling ileitis may have been masked by the extremely high dosage rate of *Lawsonia*. Therefore, we chose to modify the subsequent disease challenge study by lowering the dosage rate.

Results from this experiment suggest that dietary inclusion of DDGS had no effect on the pig's ability to resist an ileitis challenge. However, the inoculation dosage used in this study was much higher than our original target, and may have masked any potential dietary effects that would otherwise have been observed. Based upon the difficulty in achieving our target *Lawsonia* dosage in our first experiment, we chose to conduct a second experiment to determine the effects of DDGS and/or antibiotic regimen on ability of the young growing pig to resist an ileitis challenge. The objectives of this study were to: (1) modify the disease challenge model to provide an infection dose comparable to level of exposure in commercial finishing barns, (2) determine if dietary inclusion of DDGS can reduce the incidence or severity of ileitis in growing pigs, and (3) compare dietary DDGS inclusion to an antibiotic regimen currently used to treat ileitis.

For the second experiment, we utilized 100 crossbred pigs (50 gilts, 50 barrows) that were weaned at 17 days of age and transported to the CVM-RAR isolation barns located on the University of Minnesota St. Paul campus, and randomly allotted (blocked by sex and weight) to one of five treatments. Pigs were housed in separate rooms (10 pigs/room, 2 rooms/treatment). All pigs were fed a commercial Phase 1 pelleted diet during the first 4 days of the trial, and were subsequently placed on their respective diets for the remainder of the study. Experimental diets were formulated to be equivalent in energy (3390 kcal/kg ME), calcium (0.80%), total phosphorus (0.70%), and apparent ileal digestible lysine (1.15%). Pigs were fed either a corn-soybean meal diet or a corn-soybean meal-10% DDGS diet, with or without antibiotics. The antibiotic regimen consisted of continuous BMD® inclusion (30 g/ton of mixed feed) along with pulsing of Aureomycin® (500 g/ton of mixed feed) from day 3 pre-challenge to day 11 post-challenge.

Treatment:	**Diet:**	**Antibiotic:**
(1) Negative Control (NC)	Corn-soybean meal	No
(2) Positive Control (PC)*	Corn-soybean meal	No
(3) DDGS (D10)*	10% DDGS	No
(4) Antibiotic (A)*	Corn-soybean meal	Yes
(5) DDGS & Antibiotic (D10 + A)*	10% DDGS	Yes

* indicates pigs were inoculated with a mucosal homogenate 4 weeks after initiation of dietary treatments

Data involving pigs on the disease challenge treatments were analyzed as a 2 x 2 factorial (with DDGS level (0 or 10%) and antibiotic regimen as the factors). All animal management procedures and data collection were conducted similar to those described for Experiment 1,

except that the dosage rate was reduced when infecting pigs in the disease challenge treatment groups.

Two pigs were removed from the experiment prior to completion due to health reasons unrelated to the ileitis challenge. Body weights, growth performance, feed intake, and feed efficiency results are shown in Table 12. Average initial pig weight was 6.7 kg at the beginning of the trial. During the pre-challenge period, growth, feed intake and feed efficiency were similar across all treatments.

Infecting pigs with *L. intracellularis* appeared to reduce feed intake, growth, and feed efficiency during the 3-week post-challenge period, but these effects were not significantly different. Providing the combination of DDGS and antibiotic regimen together for challenged pigs resulted in similar feed intakes to negative control pigs, and appeared to partially make up for the drop in growth performance observed in other challenged pigs, but these mean differences were also not significantly different. Neither DDGS nor antibiotic regimen alone appeared to have no effect on growth performance. It should be noted that only two replications per treatment were used in the analysis of growth performance (room was the experimental unit), and that more replications are needed to determine if numerical differences in treatment means observed are in fact dietary responses that could be expected on a consistent basis under similar conditions. This experiment, however, was designed to use lesion (necropsy) data, fecal PCR, and immunohistochemistry (IHC) measurements as the primary response criteria.

Table 12. Effect of Adding 10% DDGS and/or BMD/Aureomycin to Swine Diets on Gain, Feed Intake, and Feed Conversion of Growing Pigs Under an Ileitis Challenge.

	NC	PC	D10	A	D10 + A
# pens	2	2	2	2	2
Initial wt., kg	6.6	6.9	6.8	6.6	6.7
Challenge wt., kg	19.5	20.8	19.2	19.9	20.0
Final wt., kg	36.3	34.9	30.6	33.4	35.1
Pre-challenge					
ADG, g	404	432	386	417	416
ADFI, g	695	645	726	731	692
G/F	0.58	0.67	0.53	0.57	0.60
Post-challenge					
ADG, g	799	672	542	642	720
ADFI, g	1262	1148	1046	1167	1276
G/F	0.63	0.59	0.52	0.55	0.58

Looser fecal consistency was observed (data not shown) from day 3 to day 20 post-challenge in challenged pigs compared to uninfected pigs, and pigs fed the combination of DDGS and antibiotic regimen tended to have improved stool scores during the final week of the study ($P < 0.15$). Necropsy results for Experiment 2 are presented in Table 13. Two pigs in the negative control (NC) group had lesions that were suspect for ileitis. Overall, 59% percent of pigs that

were challenged exhibited lesions consistent with ileitis, which was similar to Experiment 1. Uninfected pigs (NC) had significantly lower length, severity, and prevalence of lesions in the jejunum, ileum, colon, and total tract ($P < .01$) than challenged pigs. Feeding the 10% DDGS diet reduced ($P < .02$) lesion length, severity, and percentage of pigs exhibiting lesions in the ileum, and tended ($P < .15$) to reduce length, severity and prevalence of lesions in the colon, resulting in an overall decrease in percentage of pigs with lesions ($P < .01$). There was also a numerical trend for pigs fed the 10% DDGS diet to have reduced lesion length. Continuous BMD® inclusion with pulsing of Aureomycin® reduced severity of lesions and percentage of pigs exhibiting lesions in the jejunum ($P < .05$), and resulted in a numerical trend ($P < .11$) toward an overall reduction in lesion length. However, there were no statistically significant DDGS x antibiotic treatment interactions for length, severity, or prevalence of lesions in infected pigs.

Table 13. Effect of Adding 10% DDGS and/or BMD/Aureomycin to Swine Diets on Lesion Location, Length, Severity, and Prevalence in Growing Pigs Under an Ileitis Challenge.

	NC	PC	D10	A	D10 + A
# pigs	19	19	20	20	20
Jejunum					
Length, cm	1.3	22.2	14.7	8.6	10.2
Score (0-4)	0.05	0.90	0.38	0.28	0.25
Prevalence, %	5	47	30	20	15
Ileum					
Length, cm	0.4	10.6	5.5	9.8	6.4
Score (0-4)	0.05	1.54	0.75	1.43	1.05
Prevalence, %	5	68	40	80	55
Cecum					
Length, cm	0.0	0.2	0.3	0.3	0.0
Score (0-4)	0.0	0.1	0.1	0.1	0.0
Prevalence, %	0	5	5	5	0
Colon					
Length, cm	0.0	2.1	0.3	1.2	0.5
Score (0-4)	0.0	0.5	0.1	0.2	0.2
Prevalence, %	0	32	5	20	10
Total					
Length, cm	1.6	35.1	20.4	19.5	11.4
Prevalence, %	11	68	40	80	50

Fecal PCR and ileum tissue IHC results are presented in Table 14. Challenging pigs with *Lawsonia* resulted in a 97.5% detection rate of *L. intracellularis* in ileal tissue, indicating that

nearly all pigs were successfully infected with ileitis. Although the combination of DDGS and antibiotic regimen reduced fecal shedding 14 days post-challenge ($P < .02$), there were no dietary effects on shedding by 20 days post-challenge. Ileum IHC results showed no dietary effects on percentage of pigs testing positive for ileitis. IHC scores (indicating proportion of cells infected with *L. intracellularis*) resulted in a significant DDGS effect ($P < .05$) and an antibiotic effect ($P < .10$) on reducing the severity (score) of the infection.

Table 14. Effect of Adding 10% DDGS and/or BMD/Aureomycin to Swine Diets on Fecal PCR and Ileal Tissue IHC Scores in Growing Pigs Under an Ileitis Challenge.

	NC	PC	D10	A	D10 + A
# pigs/treatment	20	20	20	20	20
Fecal PCR					
Day 14	0.0	63.2	25.0	25.0	40
Day 20	0.0	68.4	60.0	65.0	45
IHC					
Score (0-4)	0.00	2.58	1.95	2.00	1.90
Prevalence, %	0.0	100.0	95.0	100.0	95.0

Results from this study suggest that including 10% DDGS in growing pig diets may provide some protection and aid the pig in coping with ileitis under a disease challenge situation. These results are consistent with field reports suggesting that DDGS inclusion results in reduced severity of clinical signs during an ileitis outbreak. The beneficial effects observed during this study were similar to the results observed for an approved antibiotic regimen (BMD® with 14-day Aureomycin® pulse). The BMD®/Aureomycin® regimen used in this study has been shown in previous studies to aid in the treatment of ileitis, and results have been similar to observations from this trial. An additive effect of DDGS and BMD/Aureomycin was not observed in this study, but variation in data collected and/or number of replications may have prevented detection of growth and/or lesion differences. The lower inoculation dosage rate used for this study (compared to Experiment 1) was quite successful in infecting most pigs, and appeared to be a more appropriate level of infection, allowing for detection of dietary effects on the pig's ability to resist an ileitis infection.

How do get more information on all of the current and future research related to the feeding value of "new generation" DDGS to livestock?

For more detailed research information on feeding "new generation" DDGS to swine and other species of livestock and poultry, **visit the University of Minnesota DDGS web site at: www.ddgs.umn.edu**

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