CHAPTER 26

Impact of Diet Formulation Methods on Assessing Value of DDGS

Introduction

AS DISCUSSED IN MANY CHAPTERS IN THIS HANDBOOK, one of the most important factors for identifying DDGS sources with the greatest nutritional and economic value to maximize diet inclusion rates, minimize diet cost and provide optimal animal performance is to use of accurate energy and digestible nutrient values for the DDGS source being fed. This is essential in precision animal nutrition programs because overestimating energy and digestible nutrient content in DDGS, or any other feed ingredient, can result in reduced growth performance, which is more likely to occur when DDGS is used at high dietary inclusion rates. In contrast, underestimating nutrient content of DDGS can result in feeding excessive nutrients above the animal's requirement, as well as underestimate its economic value and increased nutrient excretion in manure.

Another equally important factor in achieving optimal nutrition in DDGS precision nutrition feeding programs is to use the most advanced methods of diet formulation available for each species. The purpose of this chapter is to summarize the various diet formulation methods that have been used by nutritionists and to provide recommended methods to achieve optimal nutrition and economic value of DDGS diets for all species.

Diet formulation methods

Energy, protein (amino acids), and phosphorus are the three most expensive nutrients provided in animal feeds. Despite the development and use of precision nutrition approaches in diet formulation for various animal species, some nutritionists continue to use less accurate and outdated diet formulation approaches. For example, formulation methods have improved over the years where instead of formulating swine and poultry diets on a crude protein basis, we now formulate diets for these species on a standardized ileal digestible amino acid basis. Furthermore, use of the net energy system instead of metabolizable energy when formulating swine diets provides a more accurate approach for accounting for the true utilizable energy value of diets containing high fiber ingredients like DDGS. Similarly, using standardized total tract digestible phosphorus values are more accurate than using available or total phosphorus values for swine and poultry. These advanced feed formulation approaches have greatly increased our ability to meet the animal's true nutrient requirements.

Diet formulation method affects animal performance and DDGS value and usage. The goal is to formulate diets to meet all of the animal's daily requirements while minimizing the amount of excess energy and nutrients in the diet to minimize cost and nutrient excretion in manure, and support optimal animal health and performance.

It is well accepted that digestible energy (DE) is a more accurate measure of the utilizable energy in a feed than gross energy. Likewise, metabolizable energy (ME) is a more accurate measure than DE and net energy (NE) is a better measure than ME. However, depending on the accuracy and availability of DE, ME or NE values for feed ingredients, level of technological understanding of nutritionists, and knowledge and acceptance of energy requirements using any of these energy systems, diet formulations can vary substantially. Unfortunately, NE values for DDGS are not as well defined as ME values, and ME content has been shown to be highly variable among DDGS sources (see **Chapter 20 and 23**).

Crude protein is a measure of the nitrogen content of a feed or feed ingredient and does not adequately reflect the amino acid content, digestibility, or quality of the protein in feed ingredients. While crude protein is an acceptable measure when formulating ruminant diets, it is unacceptable to achieve accuracy in meeting the digestible amino acid needs of pigs, poultry, and aquaculture species. In general, crude protein is a useful measure in ruminant diets because the microorganisms in the rumen can convert various forms of nitrogen into the required amounts of microbial protein, with the proper amino acid amounts and balance, to meet the amino acid needs of ruminants. However, measures of rumen degradable and undegradable protein provide more accurate measures of the true nutritional value of protein in ruminant feeds than crude protein. The digestive systems of monogastric animals do not have these capabilities, and therefore, require specific amounts of digestible amino acids in their daily diet. For swine, poultry and aquaculture, formulating diets on a total amino acid basis is more accurate than using crude protein, but much greater accuracy is achieved when these diets are formulated on a digestible amino acid basis. In addition, it is important to monitor and adjust methionine, threonine and tryptophan concentrations relative to lysine to insure proper amino acid balance in DDGS diets for swine, poultry and fish. It is also important to insure that the proper proportion of energy is provided relative to amino acid levels (e.g. kcal of ME or NE/g of digestible lysine). Using digestible amino acid in formulating DDGS diets minimizes the risk of overfeeding protein and amino acids, while minimizing diet cost and nitrogen excretion in the manure.

Similarly, monogastric diets containing DDGS should be formulated on a digestible or available phosphorus basis instead of a total phosphorus basis. By accounting for the relatively high level of available phosphorus in DDGS, the amount of inorganic phosphate supplementation, diet cost and phosphorus excretion in manure can be substantially reduced. Using a digestible or available phosphorus formulation approach in DDGS diets allows for optimizing utilization of the high digestible and available phosphorus content found in DDGS.

A summary of accurate energy and digestible nutrient values of DDGS for beef cattle (**Chapter 17**), dairy cattle (C**hapter 19**), poultry (**Chapter 20**) and swine (**Chapter 23**) are provided in other chapters of this handbook. Furthermore, prediction equations to dynamically estimate ME and digestible amino acid content of DDGS sources for swine and poultry are provided in their respective chapters. Numerous examples of published studies evaluating diet formulation modifications using DDGS to optimize animal health and performance are also provided in these chapters.

Many examples can be shown to illustrate the impact of diet formulation method on DDGS use based on nutrient variability among sources and formulation method. However, several examples of swine diet formulations have been chosen to show the comparison of using different methods and their implications on achieving the goal of precision swine nutrition. These relative comparisons also have relevance for other livestock and poultry species using nutrient profiles and formulation methods specific to those species, but it is beyond the scope of this paper to give all possible combinations of formulations for various production phases for multiple livestock and poultry species.

Impact of Variation in Energy and Digestible Amino Acid Content on Diet Composition and DDGS Use in Swine Diets

DDGS metabolizable energy (ME) values

Two extreme values for ME content of DDGS were selected from previously published data (Pedersen et al., 2007, and Anderson et al., 2009). The ME content for one DDGS source was 4,334 kcal/kg dry matter while the ME value for another DDGS source was 3,414 kcal/kg dry matter. Diets were formulated on a standardized ileal digestible (SID) amino acid basis and contain identical concentrations of ME (**Table 1)**. The SID amino acid content were based on data from *in vivo* studies that directly determined the SID amino acid values for specific sources of DDGS, where the SID amino acid digestibility coefficients were estimated to be 63 percent, 82 percent, 71 percent and 69 percent for lysine, methionine, threonine, and tryptophan, respectively. Desired nutrient levels were based on NRC (NRC 2012) requirements for a 45 kg pig with 325 g/d of lean tissue gain. Choice white grease was added to the low ME diet at the expense of corn to meet the energy requirement.

Because of the large difference in ME content of these two DDGS sources, about 3.8 percent of choice white grease (pork fat) was added to the low ME DDGS diet to maintain the same level of dietary ME content as the high ME DDGS diet. Without supplementing the diet with choice white grease, the low ME DDGS diet would likely be inadequate for meeting the pigs' energy requirement unless they increased feed intake. If that were to occur, feed conversion would like be less and pigs would consume excess amino acids and phosphorus relative their requirement. Various supplemental fat sources could be used instead of choice white grease to provide these deficient calories, but regardless of fat source, the addition of supplemental fat to low ME diets can increase the total diet cost. These results show that it is important to know the source of DDGS being used and have accurate estimates of the ME, and preferably, the NE content of DDGS and other ingredients to maximize their energy value in diet formulations and minimize diet cost.

Variability in total and digestible lysine concentrations among DDGS sources

As previously described, total and digestible amino acid concentrations also vary among DDGS sources. To show the importance of using accurate digestible amino values for the DDGS sources being fed, three different diets were formulated to contain 10 percent DDGS (**Table 2)**. Sources of DDGS were selected for use in growing swine diet formulations based on their SID lysine values obtained from previously published data reported by Urriola (2005). Total lysine content ranged from 0.76 percent to 1.02 percent and SID lysine ranged from 0.47 percent to 0.67 percent.

Diets were formulated to provide 10 percent (a very conservative dietary inclusion rate) of each of these 3 DDGS sources to maintain a 0.66 percent SID dietary lysine level (**Table 3**). Accuracy of SID amino acid values becomes increasingly important as dietary inclusion rates of DDGS increase because DDGS would contribute a greater amount of digestible amino acids to the diet relative to the pig's requirement. These results show that while maintaining DDGS at a constant dietary inclusion rate (10 percent), the amount of corn increased and the amount of soybean meal decreased when high SID lysine DDGS is used instead of low SID lysine DDGS when maintaining constant nutrient

Table 1. Comparison of swine grower diet formulations using high ME (4,334 kcal/kg dry matter) and low ME (3,414 kcal/kg dry matter) DDGS sources on diet composition

Ingredient, kg	**High ME DDGS**	**Low ME DDGS**
Corn	607.0	569.1
Soybean meal	172.5	172.5
High ME DDGS, 4,336 kcal/kg	200.0	
Low ME DDGS, 3,414 kcal/kg		200.0
Choice white grease		37.9
Limestone	10.0	10.0
Dicalcium phosphate	4.0	4.0
Salt	3.0	3.0
Vitamin/trace mineral premix	2.0	2.0
L-lysine HCl	1.5	1.5
TOTAL	**1000.0**	**1000.0**

Nutrient	**High ME DDGS**	**Low ME DDGS**
Dry matter %	87.39	84.03
Crude protein %	19.54	19.22
ME, kcal/kg	3526	3526
Lysine %	0.83	0.83
Methonine %	0.30	0.30
Threonine %	0.59	0.58
Tryptophan %	0.16	0.16
Calcium %	0.57	0.57
Total phosphorus %	0.52	0.51
Available phosphorus %	0.25	0.25
Ca:P	1.10	1.12

Table 2. Total and standardized ileal digestibility (SID) values for lysine, methionine, threonine, and tryptophan among three DDGS sources

Nutrient	**Low SID Lysine**	**Average SID Lysine**	**High SID Lysine**
ME, kcal/kg	3,834	3,893	3,838
Crude protein %	28.00	29.10	31.90
Lysine %	0.76	0.85	1.02
Methionine %	0.50	0.52	0.58
Threonine %	1.05	1.05	1.15
Tryptophan %	0.23	0.23	0.28
SID lysine %	0.47	0.60	0.67
SID methionine %	0.43	0.50	0.53
SID threonine %	0.79	0.80	0.87
SID tryptophan %	0.17	0.20	0.20

Table 3. Diet formulation of swine grower diets using low, average, and high standardized ileal digestibility (SID) lysine values for DDGS

Ingredient, kg	Low SID Lys. DDGS	Average SID Lys. DDGS	High SID Lys. DDGS
Corn	708.1	713.2	715.9
Soybean meal, 47 percent	172.7	167.5	164.8
DDGS	100.0	100.0	100.0
Dicalcium phosphate	3.0	3.1	3.2
Limestone	9.7	9.7	9.7
Salt	3.0	3.0	3.0
Vitamin/trace mineral premix	2.0	2.0	2.0
L-lysine HCL, kg	1.5	1.5	1.5
TOTAL	**1,000**	**1,000**	**1,000**
Nutrient Composition			
Crude protein %	17.03	16.94	17.11
ME, kcal/kg	3,416	3,422	3,416
Calcium %	0.50	0.50	0.50
Phosphorus %	0.45	0.45	0.45
Ca:P	1.11	1.11	1.11
Salt %	0.36	0.36	0.36
Crude fat %	4.34	4.26	4.24
Lysine %	0.90	0.90	0.91
SID lysine %	0.66	0.66	0.66
Methonine %	0.29	0.29	0.29
SID methonine %	0.26	0.26	0.26
Threonine %	0.63	0.62	0.63
SID threonine %	0.53	0.52	0.52
Tryptophan %	0.18	0.17	0.18
SID tryptophan %	0.15	0.15	0.15

content in the diets. Therefore, depending on the relative cost differences between corn, soybean meal, and DDGS, adding high SID lysine DDGS sources to swine diets generally reduces cost/ton of complete feed.

Impact of Formulation Methods on Diet Composition and DDGS Use in Swine Diets

Formulations on a crude protein basis

Several decades ago, swine diets in the U.S. were formulated on a crude protein basis because total and digestible amino acid requirements were not well established for different stages of production, and total and digestible amino acid content of feed ingredients had not been determined. However, once specific amino acid requirements were determined, nutritionists began formulating diets on a total amino acid basis, which improved accuracy of meeting the pig's requirements. Subsequent research showed that digestible amino acid content varied among ingredients and sources within ingredients. Numerous studies were then conducted to determine digestible amino acid requirements of pigs and the digestible amino acid content of ingredients to further improve precision swine nutrition. Today, the most accurate diet formulation method is to formulate swine diets on a standardized ileal digestible (SID) amino acid basis. Use of standardized ileal digestible amino acid content is more accurate than using apparent ileal digestible amino acid content because SID accounts for endogenous losses of amino acids, which are increased when feeding diets with relatively high fiber content. Use of SID amino acid content of DDGS will optimize the nutritional and economic value of swine diets as well as achieve optimal performance.

To show the potential problems that can occur when formulating swine DDGS diets on a crude protein basis, 3 diets were formulated to contain 0, 10 and 20 percent DDGS to meet the crude protein requirement (16 percent) of a 50 kg pig (**Table 4**). When the diet was formulated to maintain a constant crude protein level of 16 percent, the addition of 10 percent DDGS to the diet would meet all of the pigs' nutrient requirements, including amino acids. However, when the amount of DDGS in the diet is increased to 20 percent, it is impossible to meet the total lysine requirement of 0.75 percent for a 50 kg pig even though 0.15 percent of L-lysine HCl is added. If this diet was fed to pigs, growth rate and feed conversion would be reduced compared to feeding the 0 and 10 percent DDGS diets using this diet formulation approach.

Formulations on a total amino acid basis

To demonstrate the problems that can occur when formulating diets on a total amino acid basis for swine, four example DDGS diets (0, 10 percent, 20 percent and 20 percent with added synthetic amino acids) were formulated on a total amino acid basis to meet the nutrient requirements of a 50 kg pig (**Table 5**). Note that as dietary DDGS inclusion rates increased to 20 percent, the crude protein content also increased.

Although NRC requirements for total lysine, methionine, threonine, and tryptophan were met (and in some cases exceeded the requirements) in each of the diets, digestibility of the amino acids was not considered. As a result, the SID amino acid requirements for lysine and tryptophan were not met in either the 10 percent or 20 percent DDGS diets (**Table 5**). However, when the 20 percent DDGS diet was supplemented with synthetic L-tryptophan and more soybean meal (adjusted 20 percent DDGS), both the SID lysine and SID tryptophan requirements were met.

Formulations on a standardized ileal digestible (SID) amino acid basis

Currently, swine diets in the U.S. are formulated on a SID amino acid basis. This formulation method provides high accuracy in meeting the nutrient needs of pigs and allows nutritionists to use high dietary inclusion rates (up to 40 percent) of DDGS, if amino acid digestibility values are known for the source being fed, without compromising pig performance. As shown in **Table 6**, all diets formulated on a SID basis and containing up to 30 percent DDGS, meet the SID lysine content of 0.66 percent required for a 50 kg pig, and meet all other nutrient requirements including SID methionine, threonine, and tryptophan. Note that no additional synthetic amino acids were used in these diets beyond a constant inclusion rate of 0.15 percent L-lysine HCl. Greater dietary inclusion rates of DDGS can be achieved if supplemental synthetic threonine and tryptophan are added. These results show that in order to ensure excellent pig growth performance and carcass composition when adding DDGS up to 30 percent of the diet, diets must be formulated on a SID amino acid basis to meet the digestible amino acid requirements.

Use of synthetic amino acids and reduction in soybean meal use

Many growing-finishing swine DDGS diet formulations currently used in the U.S., include relatively high amounts of synthetic amino acids to replace a significant amount of soybean meal and increase the net energy content of the diet. Corn DDGS contains greater net energy content than soybean meal, and is often less expensive than both corn and soybean meal, which traditionally were the major energy and amino acid sources, respectively. However, diet must be formulated on a SID amino acid basis. The addition of synthetic (crystalline) amino acids to the diet has several advantages. First, it reduces excess nitrogen (protein) by reducing the amount of soybean meal or other high protein ingredients in the diet, while meeting the digestible amino acid requirements and optimizing growth performance. Secondly, use of synthetic amino acids minimizes nitrogen excretion and ammonia emissions from manure when feeding DDGS diets, which also significantly reduces total diet cost especially when soybean meal is expensive. Therefore, with increased commercial availability of crystalline lysine, methionine, threonine, and tryptophan at reasonable prices, a significant amount of soybean meal can be removed from the diet, while meeting the amino acid requirements.

An example diet was formulated to reduce the amount of soybean meal used in the 30 percent DDGS diet (**Table 7**). In this diet formulation, the amount of soybean meal provided was determined by using enough soybean meal to prevent the next (fifth) limiting amino acid (isoleucine) from becoming deficient. Diets were formulated on a SID amino acid basis to meet or exceed all NRC recommendations for 45 kg pigs. It is important to realize that one of the challenges of feeding diets containing high amounts (greater than 20 percent) of DDGS is the excessive amount of crude protein (nitrogen) it provides, due to its relatively high crude protein:lysine ratio. If the crude protein level in swine diets is too high, it can reduce growth performance because of the energetic cost of deamination and eliminating excess nitrogen from the pig's body. Therefore, by adding synthetic amino acid to DDGS diets, the amount of excess protein is reduced. In fact, by reducing soybean meal use to only 2 percent of the diet and adding enough synthetic amino acids to meet the pig's requirement, crude protein level was below a typical corn-soybean meal diet (**Table 7**).

Table 4. Ingredient and nutrient composition of a 16 percent crude protein swine grower diet containing 0, 10 and 20 percent DDGS

Ingredient, kg	**0% DDGS**	**10% DDGS**	**20%t DDGS**
Corn	783.5	733.8	684.2
Soybean meal, 47 percent	196.7	147.1	97.4
DDGS	0.0	100.0	200.0
Dicalcium phosphate	5.1	3.6	2.0
Limestone	8.2	9.0	9.9
Salt	3.0	3.0	3.0
L-lysine HCl	1.5	1.5	1.5
Vitamin/trace mineral premix	2.0	2.0	2.0
TOTAL	**1000.0**	**1000.0**	**1000.0**
Nutrient Composition			
Crude protein %	16.0	16.0	16.0
ME, kcal/kg	3,372	3,316	3,261
Lysine %	0.92	0.82	**0.72**
Methonine %	0.26	0.27	0.28
Threonine %	0.59	0.58	0.57
Tryptophan %	0.18	0.16	0.15
Calcium %	0.50	0.50	0.50
Phosphorus %	0.45	0.45	0.45
Ca:P	1.11	1.11	1.11
Salt %	0.37	0.41	0.44
Crude fat %	3.65	4.14	4.64

Table 5. Ingredient and nutrient composition of a swine grower diet containing 0, 10, and 20 percent DDGS and formulated on a total lysine basis

Ingredient, kg	**0% DDGS**	**10% DDGS**	**20% DDGS**	**Adjusted 20% DDGS**
Corn	796.5	757.5	635.4	610.9
Soybean meal, 47 percent	183.4	123.0	147.1	170.3
DDGS	0.0	100.0	200.0	200.0
Dicalcium phosphate	5.4	4.1	0.9	0.9
Limestone	8.1	9.0	10.0	9.9
Salt	3.0	3.0	3.0	3.0
Vitamin/Trace mineral premix	2.0	2.0	2.0	2.0
L-lysine HCl	1.5	1.5	1.5	1.5
L-tryptophan	0.0	0.0	0.0	1.5
TOTAL	**1,000**	**1,000**	**1,000**	**1,000**
Nutrient Composition				
Crude protein %	15.5	15.1	18.0	19.0
ME, kcal/kg	3,372	3,316	3,262	3,281
Lysine %	0.88	0.75	0.85	0.92
Methonine %	0.26	0.26	0.31	0.32
Threonine %	0.57	0.54	0.64	0.83
Tryptophan %	0.17	0.15	0.18	0.20
Calcium %	0.50	0.50	0.50	0.50
Phosphorus %	0.45	0.45	0.45	0.46
Ca:P	1.11	1.11	1.11	1.09
Salt %	0.37	0.41	0.44	0.44
Crude fat %	3.66	4.16	4.60	4.57
SID lysine %	0.66	**0.52**	**0.60**	0.66
SID methonine %	0.23	0.23	0.26	0.27
SID threonine %	0.49	0.44	0.51	0.54
SID tryptophan %	0.15	**0.11**	**0.12**	0.13

Table 6. Ingredient and nutrient composition of a swine grower diet containing 0, 10, 20 and 30 percent DDGS and formulated on a standardized ileal digestible (SID) lysine basis

Ingredient, kg	**0% DDGS**	**10% DDGS**	**20% DDGS**	**30% DDGS**
Corn	795.9	746.3	672.1	586.4
Soybean meal, 47 percent	184.0	134.4	109.8	96.6
DDGS	0.0	100.0	200.0	300.0
Dicalcium phosphate	5.4	3.9	1.7	0.0
Limestone	8.2	9.0	9.9	10.5
Salt	3.0	3.0	3.0	3.0
Vitamin/Trace mineral premix	2.0	2.0	2.0	2.0
L-lysine HCl	1.5	1.5	1.5	1.5
TOTAL	**1,000**	**1,000**	**1,000**	**1,000**
Nutrient Composition				
Crude protein %	15.48	17.17	18.86	20.55
ME, kcal/kg	3,371	3,317	3,262	3,205
Calcium %	0.50	0.50	0.50	0.50
Phosphorus %	0.45	0.45	0.45	0.49
Ca:P	1.11	1.11	1.11	1.02
Salt %	0.37	0.41	0.44	0.48
Crude fat %	3.66	4.54	4.58	5.04
Lysine %	0.88	0.90	0.92	0.94
SID lysine %	0.66	0.66	0.66	0.66
Methonine %	0.26	0.29	0.32	0.35
SID methonine %	0.23	0.25	0.27	0.29
Threonine %	0.57	0.63	0.68	0.74
SID threonine %	0.48	0.51	0.54	0.57
Tryptophan %	0.17	0.18	0.2	0.21
SID tryptophan %	0.15	0.14	0.13	0.12

Table 7. Ingredient and nutrient composition of a diet containing 30 percent DDGS, high amounts of synthetic amino acids and reduced soybean meal

Ingredient, kg	Control	Reduced Soybean Meal, 30% DDGS, and Synthetic Amino Acids
Corn	738.5	653.1
Soybean meal	238.8	20.0
DDGS	0.0	300.0
Limestone	8.2	12.0
Dicalcium phosphate	8.0	2.6
Salt	3.0	3.0
Premix	2.0	2.0
L-Lysine	1.5	5.9
L-Threonine	0.0	0.7
DL-Methionine	0.0	0.0
L-Tryptophan	0.0	0.7
TOTAL	**1,000**	**1,000**
Nutrient Composition		
Crude protein %	17.6	16.3
ME, kcal/kg	3,333	3,459
SID lysine %	0.92	0.84
SID methonine %	0.26	0.26
SID threonine %	0.56	0.52
SID tryptophan %	0.18	0.17
SID isoleucine. percent	0.61	0.46
Calcium %	0.60	0.58
Total phosphorus %	0.52	0.48
Available phosphorus %	0.21	0.26
Ca:P	1.15	1.20

Conclusions

In order to achieve the best economic and nutritional value from DDGS, the source, nutrient content and digestibility must be known. Depending on the nutrient composition of the DDGS source being used, and the diet formulation methods chosen, the relative economic and nutritional value of DDGS can vary substantially. Using accurate energy, amino acid and phosphorus digestibility values for DDGS can reduce excessive feeding of nutrients, avoid nutrient deficiencies and reduce diet costs while supporting optimal animal performance.

References

Anderson, P.V., B.J. Kerr, T.E. Weber, C.Z. Ziemer, and G.C. Shurson, 2009. Determination and prediction of energy from chemical analysis of corn co-products fed to finishing pigs. J. Anim. Sci. (submitted).

NRC. 2012. Nutrient Requirements of Swine. 10th Revised Edition, Natl. Acad. Press, Washington, DC.

Pedersen, C., M.G. Boersma, and H.H. Stein. 2007. Digestibility of energy and phosphorus in ten samples of distillers dried grains with solubles fed to growing pigs. J. Anim. Sci. 85(5):1168-1176.

Urriola, P.E. 2005. Distillers Dried Grains with Solubles digestibility, *in vivo* estimation and *in vitro* prediction. Master's thesis, University of Minnesota.