International Journal of Poultry Science 6 (7): 478-483, 2007
ISSN 1682-8356

Development of a Standardized Nutrient Matrix for Corn Distillers Dried Grains with Solubles[1]

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Abstract: The rapid increase in production of ethanol from corn and other grains has resulted in growing quantities of byproducts, primarily distillers dried grains with solubles (DDGS). The use of DDGS in poultry diets is not new, but the supply of product encourages the use of higher percentages than has typically been used in the past. As greater quantities are used in the diet, it becomes increasingly essential that accurate nutrient values be assigned to the product. This review attempts to summarize results from various laboratories to provide a nutrient matrix that can be used to evaluate the potential use of DDGS in poultry feeds.

Key words: Broilers, nutrient analysis, distillers dried grains, alternative ingredients

Introduction

Byproducts of the distilling industry such as distillers dried grains and distillers dried grains with solubles (DDGS) have long been commonly accepted feed ingredients in broiler diets. Early studies have been extensively reviewed by Scott (1965, 1970). Due to their supply and price, these products were typically fed at levels not exceeding 5% of the diet. However, early studies demonstrated that higher levels could be used in nutritionally balanced diets. Runnels (1966, 1968) reported that 20% DDGS was successfully incorporated into broiler diets with performance equal or superior to that of chicks fed diets with corn, soybean meal and fish meal. Waldroup *et al*. (1981) reported that when DDGS was included into broiler diets with the ME content held constant, up to 25% DDGS could be used without reduction in body weight or feed utilization. When included in diets in which the energy content was allowed to decline as the level of DDGS was increased, there was a decline in performance at DDGS levels of 15% or more. Potter (1966) found that isonitrogenous diets with 20% DDGS supported performance equivalent to control diets when fed to poults up to 8 wk of age. Couch *et al*. (1970) reported that up to 37% DDGS could be used in diets for broiler breeder replacements. Jensen (1978) reported that 20% DDGS was acceptable in nutritionally balanced layer diets and contributed a factor that improved Haugh units of eggs. Jensen (1981) stated that 20% DDGS could be used in diets for broiler breeder hens.

If the "modern" DDGS from fuel ethanol production is equal or superior in nutritional value to the "old" DDGS, it is reasonable to expect that satisfactory performance can be obtained when reasonable levels are included in nutritionally-adequate diets. Lumpkins *et al*. (2004) indicated that DDGS from modern ethanol plants can be safely used at 6% in broiler starter diets and 12 to 15% in grower and finisher periods. Lumpkins *et al*. (2005) suggested a maximal inclusion rate of 10-12% DDGS in diets for laying hens. Roberson *et al*. (2005) reported that 15% DDGS did not adversely affect performance of laying hens but suggested that lower levels of DDGS be used when introducing it into the diet. Swiatkiewicz and Korleski (2006) reported that up to 15% DDGS could be used in layer feeds; inclusion of 20% negatively affected laying rate and egg weight. Roberson (2003) noted that DDGS could be effectively included at 10% in growing-finishing diets for turkey hens if proper formulation matrix values for all nutrients were used. Noll and Brannon (2006) reported that performance of turkeys fed 20% DDGS was not different from the corn-soybean control unless used in combination with high levels of poultry byproduct meal (8-12%).

Like any byproduct, several concerns exist regarding the use of DDGS in poultry feed. These relate primarily to the extent of overall nutrient variability. Major concerns include variation in metabolizable energy content and bioavailability of lysine content and bioavailability of phosphorus and variation in sodium content. In order to properly utilize DDGS, accurate information regarding the nutrient values for the specific product available is essential. While a general knowledge of the average nutrient content of DDGS in general is helpful, the extreme variability that has been observed in various studies raises a great deal of concern as higher usage levels are contemplated. To aid in more effective utilization of "new generation" DDGS, a survey was made of recent published literature and composite values for various nutrients determined.

Review of published reports and compilation of data: Reliable nutrient values for DDGS are important for optimum use of this product in swine and poultry diets and recent studies have provided information on

Table 1: Proximate composition and amino acid content of DDGS (%, as fed basis)

	Reference[1]									
	1		2		3		4	5		
	n = 118		n = 150		n = 20		n = 5	n = 8		
Component	Mean	CV[2]	Mean	SD[3]	Mean	CV	Mean	Mean	SD	Weighted average
Dry matter	88.90	1.7	89.91	1.71	88.00	0.9				89.36
Crude protein	26.85	6.4	26.05	2.32				28.12		26.45
Fat	9.69	7.8	9.88	2.80	14.00	4.8				10.08
Fiber	7.82	8.7	6.34	1.55						6.99
Ash	5.15	14.7	4.39	0.87	4.00	5.0				4.67
Arginine	1.07	9.1	1.11	0.13			1.00	1.09	0.16	1.09
Histidine	0.68	7.8					0.65	0.69	0.06	0.68
Isoleucine	1.00	8.7	0.92	0.18			0.98	0.97	0.06	0.96
Leucine	3.16	6.4	2.87	0.63			3.07	3.05	0.14	3.00
Lysine	0.76	17.3	0.71	0.17	0.73	11.6	0.64	0.71	0.16	0.73
Methionine	0.49	13.6	0.50	0.12	0.49	9.7	0.48	0.54	0.06	0.50
Cystine			0.54	0.10	0.52	11.3		0.56	0.04	0.54
Phenylalanine	1.31	6.6					1.34	1.31	0.04	1.31
Threonine	1.00	6.4	0.93	0.17	0.98	6.0	0.95	0.96	0.06	0.96
Tryptophan	0.22	6.7	0.21	0.03			0.25	0.20	0.05	0.21
Valine	1.33	7.2	1.27	0.22			1.30	1.33	0.07	1.30
Serine							1.04	1.09	0.07	1.07

[1]1= Spiehs *et al*. (2002); 2= Fiene *et al*. (2006); 3= Parsons *et al*. (2006); 4= Fastinger *et al*. (2006); 5= Batal and Dale (2006). [2]Coefficient of variation. [3]Standard deviation

Table 2: Prediction of total amino acid content of DDGS from proximate values of crude protein, fat and fiber (Fiene *et al*., 2006)

Amino acid	Equation	R^2
Arginine	Y = 0.07926 + 0.0398 * CP	0.48
Isoleucine	Y= -0.23961 + 0.04084*CP+0.01227*Fat	0.86
Leucine	Y= -1.15573 + 0.13082*CP+0.06983*Fat	0.86
Lysine	Y= -0.41534 + 0.04177*CP+0.00913*Fiber	0.45
Methionine	Y= -0.17997 + 0.02167*CP+0.01299*Fat	0.78
Cystine	Y = 0.11159 + 0.01610*CP+9.00244*Fat	0.52
TSAA	Y= -0.12987 + 0.03499*CP+0.05344*Fat-0.00229*Fat^2	0.76
Threonine	Y= -0.05630 + 0.03343*CP+0.02989*Fat-0.00141*Fat^2	0.87
Tryptophan	Y= 0.01676 + 0.0073*CP	0.31
Valine	Y= 0.01237 + 0.04731*CP+0.00054185*Fat^2	0.81

proximate and amino acid composition of DDGS from new ethanol plants (Table 1). It is apparent that there is considerable variability in many of the essential nutrients. Because corn itself varies in nutrient content, concentrating these nutrients approximately three-fold during the production of ethanol exacerbates the variability in the residual DDGS. For example, Reese and Lewis (1989) reported that corn produced in Nebraska in 1988 ranged from 7.8 to 10.0% crude protein, from 0.22 to 0.32% lysine and from 0.24 to 0.34% phosphorus. In addition, the ratio of blending the distiller's solubles with the residual grains to produce DDGS may vary among producers. Some producers add all of the solubles back, while some divert a portion for other uses including use as a fuel source for the ethanol plant. For most of the major nutrients, Spiehs *et al*. (2002) reported almost as much variation within a source as between different plants. Thus, a continual quality control program to characterize the product will be essential if optimum usage is to be made of DDGS in a poultry formula.

Extensive analyses of the amino acid contents of DDGS samples have recently been reported by several investigators (Table 1). Mean values for lysine and methionine, the two most critical amino acids for poultry and swine, were similar, but considerable variability was observed. Fiene *et al*. (2006) conducted stepwise regression analysis on data from approximately 150 samples to predict total amino acid content from the proximate values of moisture, crude protein, fat and fiber and reported the equations shown in Table 2. The R^2 values suggest that some amino acids (Ile, Leu, Met, TSAA, Thr and Val) could be predicted with some success from the proximate values. However, others such as Arg, Cys, Lys and Trp could not be predicted with a high degree of accuracy due largely to a lack of consistency of the amino acid to protein ratio in the samples tested.

Nutritionists are concerned not only with total amino acid content but also the digestibility. Of greatest concern with DDGS is the bioavailability of lysine, as during the process of drying DDGS the material is typically exposed

Table 3: Digestible amino acid coefficients (%) of DDGS

	Reference[1]							
	1		2		3		4	
	n = 8		n = 47		n = 20		n = 5	
Amino acid	Mean	SD[2]	Mean	SD	Mean	CV[3]	Mean	Weighted average
Arginine	84.1	6.6	85.2	3.46			88.3	85.3
Histidine	84.1	5.7					85.3	84.5
Isoleucine	83.3	4.9	81.8	3.56			84.1	82.2
Leucine	88.6	2.0	89.3	2.49			90.2	89.3
Lysine	69.6	11.5	65.9	9.50	72	11.2	76.5	68.5
Methionine	86.8	3.4	86.1	2.70	88	1.9	88.5	86.8
Cystine	73.9	9.7	77.6	4.98	77	7.7	81.6	77.3
Phenylalanine	87.5	3.3					88.0	87.7
Threonine	74.5	6.0	74.6	4.15	76	4.8	77.5	75.1
Tryptophan	82.8	5.1	83.9	5.08			88.2	84.1
Valine	79.3	3.3	81.8	2.85			81.4	81.4
Serine	81.9	4.3					84.3	82.8

[1]1= Batal and Dale (2006); 2= Fiene *et al*. (2006); 3= Parsons *et al*. (2006); 4= Fastinger *et al*. (2006). [2]Standard deviation. [3]Coefficient of variation

Table 4: Prediction of True Metabolizable Energy of DDGS from proximate values of crude protein, fat, fiber and ash content (Batal and Dale, 2006)

Prediction equation	R^2
TME_n = 2439.4+43.2*Fat	0.29
TME_n = 2957.1+43.8*Fat-79.1*Fiber	0.43
TME_n = 2582.3+36.7*Fat–72.4*Fiber + 14.6*Protein	0.44
TME_n = 2732.7+36.4*Fat-76.3*Fiber + 14.5*Protein-26.2*Ash	0.45

to temperatures of approximately 315°C (600° F). The adverse effect of excess heat on amino acid availability and especially on lysine is well known (McGinnis and Evans, 1947; Warnick and Anderson, 1968). Several recent studies have evaluated the digestibility of amino acids in DDGS and the results are summarized in Table 3.

The digestibility of lysine is the lowest among the essential amino acids and also has the greatest variability. A rapid means of assessing the lysine digestibility in a particular sample of DDGS is of prime importance in optimizing the use of this ingredient and two methods recently have been proposed in this regard. One of these is the use of the Immobilized Digestibility Enzyme Assay (IDEA™, Novus International, St. Louis MO) described by Shasteen *et al*. (2002). This assay was used to estimate the lysine digestibility of 28 DDGS samples that had previously been subjected to *in vivo*-determined true lysine digestibility (Fiene *et al*., 2006). There was a high correlation between *in vivo*-determined true lysine digestibility and that estimated by the IDEA™ method. The correlation between digestibility of other amino acids and the IDEA™ method was not as successful, ranging from 0.12 for Met to 0.43 for Cys. More than 180 samples of DDGS have been subjected to the IDEA™ assay by Novus International (Fiene *et al*., 2006), resulting in an estimated lysine digestibility of 66.7±9.3 (mean±SD). This is in good agreement with the weighted average of 68.5% shown in Table 3.

In order to evaluate variation among producers, multiple DDGS samples were collected from eight different suppliers over a 3 to 4 month time period and subjected to the IDEA™ assay (Fiene *et al*., 2006). The data showed that within a supplier the variation in lysine digestibility was relatively small with a few exceptions. It is recommended that the IDEA™ assay be used periodically to estimate the digestible lysine content of samples received in a feed mill, especially since the product may come from a wide variety of sources.

A second method that has been used to estimate lysine digestibility is evaluation of the color of the product. Formation of lysine-carbohydrate complexes under heat has long been known (Maillard, 1912a,b). Color of soybean meal has long been linked to proper processing temperature (McNaughton *et al*., 1981). Numerous studies have linked the color of DDGS with lysine digestibility (Cromwell *et al*., 1993; Ergul *et al*., 2003; Batal and Dale, 2006; Fastinger *et al*., 2006). Batal and Dale (2006) reported that samples with more lightness (L* = 60.3) and more yellowness (b* = 25.9) were associated with a DDGS having an average of 0.66% digestible Lys whereas products that were darker (L* = 50.4) and less yellow (b* = 7.41) were associated with a product having 0.18% digestible Lys. Use of visual color or use of color meters may be used to identify samples of DDGS that have been subjected to excessive heat with subsequent reduction in lysine bioavailability.

Several studies provide estimates of the metabolizable energy content of DDGS. Batal and Dale (2006) reported an average TME_n for 17 samples of 1282±82 kcal/lb, with a range of 1132 to 1450 kcal/lb. Fastinger *et al*. (2006) found an average of 1302 kcal/lb for five samples with a range of 1127 to 1382 kcal/lb. Lumpkins and Batal (2005) reported a TME_n value of 1318 kcal/lb for a single

Table 5: Mineral composition of DDGS from various authors (% as fed basis)

	Reference[1]								
	1		2		3		4		
	n = 118		n = 12		n = 20		n - 20		
Mineral	Mean	CV[2]	Mean	SD[3]	Mean	SD	Mean	CV	Weighted average
Calcium	0.05	57.2	0.29	0.27			0.03	38.4	0.07
Phosphorus	0.79	11.7	0.68	0.07	0.73	0.04	0.73	5.3	0.77
Potassium	0.84	14.0	0.91	0.11					0.85
Sodium	0.21	70.5	0.25	0.15			0.11	32.8	0.20

[1]1= Spiehs *et al*. (2002); 2= Batal and Dale (2003); 3= Martinez-Amezcua *et al*. (2004); 4= Parsons *et al* (2006). [2]Coefficient of variation. [3]Standard deviation

Table 6: Nutrient matrix for DDGS based on composite of reported values

Nutrient	Unit	Amount
Dry matter	%	89.36
Crude protein	%	26.45
Fat	%	10.08
Fiber	%	6.99
TME_n	Kcal/lb	1293.00
Calcium	%	0.07
Phosphorus	%	0.77
Available phosphorus	%	0.48
Potassium	%	0.85
Sodium	%	0.20
Arginine	%	1.09
Histidine	%	0.68
Isoleucine	%	0.96
Leucine	%	3.00
Lysine	%	0.73
Methionine	%	0.50
Cystine	%	0.54
Phenylalanine	%	1.31
Threonine	%	0.96
Tryptophan	%	0.21
Valine	%	1.30
Serine	%	1.07
Digestible Arginine	%	0.93
Digestible Histidine	%	0.58
Digestible Isoleucine	%	0.78
Digestible Leucine	%	2.70
Digestible Lysine	%	0.50
Digestible Methionine	%	0.43
Digestible Cystine	%	0.42
Digestible Phenylalanine	%	1.15
Digestible Threonine	%	0.72
Digestible Tryptophan	%	0.18
Digestible Valine	%	1.05
Digestible Serine	%	0.88

sample of DDGS. Parsons *et al*. (2006) reported an average TME_n of 1299 kcal/lb for 20 samples with a range from 1182 to 1385 kcal/lb. A weighted average of these 43 samples is 1293 kcal/lb. Batal and Dale (2006) applied regression analyses to the proximate composition of the DDGS and the determined TME_n values from their study and developed the equations shown in Table 4 which can be applied to samples of DDGS to estimate the TME_n value. The R^2 for these equations is rather low and might be strengthened by inclusion of data from additional samples of DDGS.

Several recent reports on the mineral content of DDGS are summarized in Table 5. The bioavailability of the P in DDGS appears to be higher than previously assumed (NRC, 1994). This may be in part because of the P provided by the residual yeast, which is considered to be highly available and because the fermentation may release some phosphorus from the phytate bond. Singsen *et al*. (1972) reported that the biological availability of the phosphorus in three composite samples of DDGS from beverage alcohol production was fully equivalent to that in commercial dicalcium phosphate and should be considered as 100% available when formulating poultry diets. Martinez-Amezcua *et al*. (2004) noted a substantial variability in P bioavailability among nine samples, ranging from 69 to 102% relative to KH_2PO_4 and reported that increased heat processing of DDGS may increase the bioavailability of P in DDGS. Lumpkins and Batal (2005) reported that the relative bioavailability of phosphorus in a DDGS sample containing 0.74% total P was 68 and 54% in two different trials. Martinez-Amezcua *et al*. (2006) found a relative P bioavailability of 62% in a sample of DDGS containing 0.67% total P. The bioavailability was increased by supplementation of the diet with 3% citric acid or with phytase. Because of the importance of phosphorus in broiler diets and the extreme sensitivity of broilers to a phosphorus deficiency we have chosen to use a value of 62% relative bioavailability in derivation of the standard nutrient matrix.

Sodium is one of the least expensive minerals but deficiency states have perhaps more rapid impact on performance of any essential nutrient. With the demand to reduce litter moisture in poultry houses, nutritionists often are pressured to minimize dietary sodium levels. Considerable variation in sodium content of DDGS has been observed (Table 5). Batal and Dale (2003) noted that the source of the extraordinary variability in sodium content of DDGS is not immediately clear and suggested that nutritionists need to properly characterize the mineral content of the DDGS from respective sources prior to incorporation into balanced diets. However, data from Spiehs *et al*. (2002) showed considerable in-plant variation indicating that it would be difficult to characterize the sodium content of a single plant by a few analyses. It is recommended that frequent sodium assays be made of the product received in feed mills, especially if the sodium from the DDGS is to be considered in meeting the requirements for this nutrient.

A number of studies have reported on the nutrient content of various samples of DDGS, many of which have been cited in this report. We have summarized these as weighted averages for various nutrients and combined these into a suggested nutrient matrix to use as a starting point for evaluating DDGS in poultry feed (Table 6).

Nutritionists should continuously scrutinize the proximate composition of the product along with periodic assays for calcium, phosphorus and sodium and for estimates of lysine digestibility by IDEA™, color meter, or visual inspection of color and make adjustments in the table as warranted.

As ethanol production from corn increases, there is growing interest in modifying the technology used to produce the product. This will result in different types of byproducts that may have superior or inferior nutritional value (Parsons *et al*., 2006). Use of these new manufacturing processes will result in the production of byproducts that will undoubtedly differ markedly in nutrient content from those produced today. It will be necessary for the nutritionist to be sure they have accurate nutritional values for the products that they will be using in their diets. Ethanol producers should work with the feed industry to provide characteristic nutrient values for such new products as they develop.

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