The Bioavailability of Lysine and Phosphorus in Distillers Dried Grains with Solubles

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ABSTRACT Five experiments were conducted to determine Lys and P bioavailabilities of distillers dried grains with solubles (DDGS), which was derived from corn fermentation in a modern nonbeverage ethanol plant. In experiment 1, we used the precision-fed cecectomized rooster assay and estimated the true digestibility of Lys in DDGS to be 75%. In experiments 2, 3, 4, and 5 the relative bioavailabilities of Lys and P were assessed using slope-ratio chick growth experiments. In experiments 2 and 3, Lys-deficient basal diets containing 0.40 or 0.60% digestible Lys respectively, were formulated. A linear growth response ($P < 0.05$) was observed from the addition of 0.10 and 0.20% L-Lys from L-Lys·HCl and 10 and 20% DDGS to the basal diets. Body weight gain was regressed on Lys intake from L-Lys·HCl and DDGS, and the ratio of the slopes indicated the relative bioavailable Lys in DDGS. The values as a percentage of total Lys (0.83) in DDGS yielded availability estimates of 80% for experiment 2 and 100% for experiment 3. In experiments 4 and 5, a P-deficient basal diet containing 0.12% nonphytate P was formulated. A linear growth and tibia bone ash (%) response ($P < 0.05$) were observed from the addition of 0.05 and 0.10% P from K_2HPO_4 and 2 levels of DDGS (5 and 10% for experiment 4 and 7 and 14% for experiment 5). Tibia bone ash (%) was regressed on P intake from K_2HPO_4 and DDGS, and the ratio of slopes indicated the relative bioavailability of P in DDGS. The values as a percentage of total P (0.74%) in DDGS yielded availability estimates of 68% for experiment 4 and 54% for experiment 5.

(*Key words*: distillers dried grains with solubles, lysine, phosphorus, bioavailability, chick)

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INTRODUCTION

The majority of distillers dried grains with solubles (DDGS) produced has traditionally been derived from the beverage industry based on a mixture of several grains used during the fermentation process. Recently, the United States has encouraged nonbeverage ethanol production, as ethanol is cleaner burning, provides more energy than petroleum, and is a renewable resource (Reilly, 1979). Ethanol producers responded to government encouragement in the mid to late 1990s by building new plants. Large quantities of DDGS from these new nonbeverage ethanol plants have become available to the feed industry (Shurson, 2003), which has renewed interest in using DDGS in poultry diets. The DDGS coming from these modern plants is almost exclusively from corn fermentation and is dried under lower temperatures, both of which seem to allow DDGS to be a more consistent product (Noll et al., 2003).

The bioavailability of Lys in DDGS has been questioned. In the process of drying DDGS the material is exposed to temperatures of approximately 315°C (600°F). It has been reported that excessive heating leads to a decrease in amino acid (AA) availability, specifically Lys (McGinnis and Evans, 1947; Warnick and Anderson, 1968), similar to what has been reported with soybean meal (Fernandez and Parsons, 1996). Research in the past has been conducted to determine the AA availability of DDGS, but much of the DDGS used was a byproduct of the beverage industry with several grains used during fermentation. Combs and Bossard (1969) performed a chick growth assay and reported Lys bioavailability values ranging from 74 to 90%. Parsons et al. (1983) estimated a lower bioavailability of 66% when using similar methodology and also determined the true digestibility of Lys in DDGS to be 82% using the total fecal collection assay. The variation in reported availability values and recorded estimates (NRC, 1994) may be due to the differences in the drying process and the grain composition of DDGS.

In recent years environmental concerns have been directed toward the poultry industry. Poultry manure has become a concern due to the P content present, which may contribute to environmental contamination. Thus, efficient P utilization (i.e., reduced excretion) is of great concern. In an effort to reduce P in poultry waste, diets for commercial broilers have been formulated with re-

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Abbreviation Key: DDGS = distillers dried grains with solubles.

TABLE 1. Nutritional composition of distillers dried grains with solubles (DDGS; as-fed basis)

Component	%
TME_n, kcal/kg	2,905[1]
Dry matter	86.00
Crude protein	30.00
Ether extract	9.80
Crude fiber	5.34
Phosphorus	0.74
Ash	3.90
Sodium	0.11
Amino acid	
Lys	0.83
Met	0.56
TSAA	1.18
Thr	1.05
Arg	1.25
Trp	0.28

[1]The TME_n for DDGS was determined in 10 conventional roosters.

duced levels of inorganic P and supplemented with phytase. Because P is an expensive component of poultry diets, knowledge of the availability of P in DDGS will allow feed producers to more accurately formulate diets so as to meet the bird's P needs while reducing environmental contamination. Research conducted to determine the P bioavailability of DDGS is limited.

Due to the increased interest and availability of this feedstuff, the present studies were conducted to determine the relative bioavailability of Lys and P in DDGS from modern nonbeverage fuel ethanol plants.

MATERIALS AND METHODS

Analytical and Digestibility Evaluation of DDGS

The DDGS used in all the experiments was produced in a nonbeverage fuel ethanol plant in Aurora, NE, that was built in the early 1990s and uses corn as the fermentation substrate. The sample was golden yellow, coarse, and a distinctively sweet smell. The DDGS used in these experiments was analyzed[2] for dry matter, crude protein, ether extract, crude fiber, ash, sodium, and P (Table 1) by the methods of the Association of Official Analytical Chemists (1984). In addition, 9 samples of DDGS obtained from modern nonbeverage ethanol plants in the Midwest United States were analyzed for total P and phytate P concentration[2] as described by Latta and Eskin (1980). Analysis of all samples was conducted in duplicate.

Experiment 1

The true digestibility of Lys in DDGS was determined using the precision-fed cecectomized rooster assay. Single Comb White Leghorn roosters were cecectomized at 20 wk of age as described by Parsons (1985) and not used for digestibility trials for at least 2 mo after surgery. The roosters were allowed ad libitium access to feed and water prior to the true digestibility experiment. All birds were fasted for 24 h, and 5 roosters were crop intubated with 30 g of DDGS. The crop intubation procedure has been described by Sibbald (1986). Five additional roosters were fasted throughout the experimental period, which allowed for measurement of endogenous AA excretion. Excreta were collected quantitatively for 48 h postfeeding (Likuski and Dorrell, 1978). Excreta samples were dried at 75°C for 48 h, weighed, and ground. The DDGS and 5 excreta samples were then sent to the Experiment Station Chemical Laboratories at the University of Missouri[3] for determination of AA concentrations. The true digestibility of Lys in DDGS was determined twice via the precision fed cecectomized rooster assay explained above. The calculated digestibility values from each experiment were averaged, and one value was reported.

Chick Bioavailability Experiments 2, 3, 4, and 5; General Procedures

Four experiments were conducted to determine the relative bioavailability of Lys and P in DDGS using multiple regression slope-ratio methodology. All animal housing, handling, and euthanasia procedures were approved by the Institutional Animal Care and Use Committee. The basal diets for the Lys and P experiments provided vitamins, minerals except P (for experiments 4 and 5), and all indispensable AA except Lys (for experiments 2 and 3) in amounts adequate to meet or exceed NRC (1994) nutrient recommendations for maximal chick growth. Male Cobb 500 chicks were housed in environmentally controlled rooms in thermostatically controlled starter batteries[4] with raised wire floors and were allowed ad libitum access to water and feed. Uniform light was provided 24 h daily. From d 1 to 7 posthatching, chicks received a standard starter broiler diet (3,200 kcal of ME_n/kg, 23% crude protein, and 0.2% supplemental methionine). On d 8, after an overnight period of feed withdrawal, chicks were weighed and randomly allotted to pens such that each pen had similar initial weights. Each of the diets were fed to 6 replicate pens of 6 chicks. Body weight and feed intake for all the groups were measured, and weight gain and feed efficiency (gain:feed) were calculated. At the occurrence of mortality, the bird was weighed, and body gain and feed intake were adjusted accordingly.

Experiments 2 and 3

The relative bioavailability of Lys was determined by slope-ratio assay using a semipurified cornstarch-dextrose-corn gluten meal Lys-deficient basal diet (Table 2), which was formulated to contain 0.40 and 0.60% digestible Lys for experiments 2 and 3, respectively. A

[2]UGA Nutritional Lab, University of Georgia, Athens, GA.
[3]Experiment Station Chemical Laboratories, University of Missouri-Columbia, Columbia, MO.
[4]Petersime Incubator Co., Gettysburg, OH 45328.

TABLE 2. Composition of the Lys-deficient basal diets (as-fed basis)

Ingredients	Experiment 2[1]	Experiment 3[2]
	(%)	
Cornstarch	to 100.00	to 100.00
Corn gluten meal[3]	25.00	25.00
Dextrose	29.98	30.56
Fat, poultry	3.00	3.00
Limestone	1.32	1.32
Dicalcium phosphate	2.25	2.25
Salt	0.40	0.40
Vitamin mix[4]	0.50	0.50
Mineral mix[5]	0.08	0.08
L-Lysine·HCl	0.22	0.47
DL-Met	0.30	0.30
Glycine	2.00	2.00
L-Glu	5.50	4.92
L-Thr	0.30	0.30
L-Trp	0.12	0.12
L-Ile	0.22	0.22
L-Arg	0.77	0.77
L-Val	0.22	0.22
L-His	0.05	0.05
Zinc bacitracin[4]	0.05	0.05
$MgSO_4 \cdot 7H_2O$	0.30	0.30
K_2HPO_4	0.51	0.51
$NaHCO_3$	0.50	0.50
Coccidostat[7]	0.08	—

[1]The diet contained a minimum (by calculation): 22.5% crude protein, 3,370 kcal of ME_n/kg, 0.40% digestible Lys, and 0.90% digestible total sulfur amino acids.

[2]The diet contained a minimum (by calculation): 22.5% crude protein, 3,370 kcal of ME_n/kg, 0.60 digestible Lys, and 0.90% digestible total sulfur amino acids.

[3]Corn gluten meal contained 1.05% total Lys, 0.88% digestible Lys (based on a total fecal collection method using cecectomized roosters).

[4]Vitamin mix provided the following (per kg of diet): thiamin·mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B_{12} (cobalamin), 12.0 μg; pyridoxine·HCL, 2.7 mg; D-biotin, 0.11 mg; folic acid, 0.55 mg; menadione sodium bisulfate complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 1,100 IU; trans-retinyl acetate, 5,500 IU; all-*rac*-tocopherol acetate, 11 IU; ethoxyquin, 150 mg.

[5]Trace mineral mix provides the following (per kg of diet): manganese ($MnSO_4 \cdot H_2O$), 60 mg; iron ($FeSO_4 \cdot 7H_2O$), 30 mg; zinc (ZnO), 50 mg; copper ($CuSO_4 \cdot 5H_2O$), 5 mg; iodine (ethylene diamine dihydroiodide), 1.5 mg, selenium (Na_2SeO_3) 0.13 mg.

[6]Contributed 27.5 mg of bacitracin methylene disalicylate/kg.

[7]Coban 60, Elanco Animal Health, Indianapolis, IN.

linear standard growth curve was constructed by the addition of 0.10 and 0.20% L-Lys from L-Lys·HCl to the basal diets, at the expense of cornstarch, to achieve digestible Lys levels of 0.40, 0.50, and 0.60% in experiment 2 and 0.60, 0.70 and 0.80% in experiment 3. In addition, 2 levels of DDGS (10 and 20%) were added to the basal diets for experiments 2 and 3 at the expense of cornstarch to provide levels of digestible Lys that would fall within the boundaries of the standard curve. The chicks were fed the experimental diets from 8 to 19 d posthatching in experiment 2 and 8 to 17 d posthatching for experiment 3.

Experiments 4 and 5

The relative bioavailability of P in DDGS was determined in 2 chick growth experiments. A corn-soybean meal P-deficient basal diet containing 0.12% nonphytate P (Table 3) was supplemented with 0.05 and 0.10% P from K_2HPO_4 at the expense of cornstarch to create conditions projected to result in a linear standard growth curve. Two levels of DDGS in experiment 4 (5 and 10%) and experiment 5 (7 and 14%) were added to the basal diets at the expense of cornstarch to provide a linear test (DDGS) growth curve. In experiments 4 and 5, the chicks were fed each of the 5 experimental diets from 8 to 21 d posthatching. At the end of each experiment, all chicks were euthanized with CO_2 gas, and the left tibia bone was collected. The muscle and tissue were removed from the tibia leaving only the cartilage cap and bone. The bones then underwent fat extraction as described by the Association of Official Analytical Chemists (1984) and were ashed at 600°C in a muffle furnace for 24 h to allow for determination of tibia bone ash content.

TABLE 3. Composition of basal diets used in experiments 4 and 5 (as-fed basis)

Ingredient	Experiment 4[1]	Experiment 5[2]
	(%)	
Cornstarch	to 100.00	to 100.00
Corn	47.55	41.63
Soybean meal	38.00	40.00
Fat, poultry	2.00	2.00
Limestone	1.42	1.42
Salt	0.30	0.30
Vitamin mix[3]	0.25	0.25
Mineral mix[4]	0.08	0.08
Zinc bacitracin[5]	0.05	0.05
DL-Met	0.28	0.28
Coccidostat[6]	0.08	—

[1]The diet contained a minimum (by calculation): 22% crude protein, 3,010 kcal of ME_n/kg, 0.12% nonphytate P, and 0.65% Ca.

[2]The diet contained a minumum (by calculation): 22.5% crude protein, 2,965 kcal ME_n/kg, 0.12% nonphytate P, and 0.65% Ca.

[3]Vitamin mix provided the following (/kg of diet): thiamin·mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B_{12} (cobalamin), 12.0 μg; pyridoxine·HCL, 2.7 mg; D-biotin, 0.11 mg; folic acid, 0.55 mg; menadione sodium bisulfate complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 1,100 IU; *trans*-retinyl acetate, 5,500 IU; all-*rac*-tocopherol acetate, 11 IU; ethoxyquin, 150 mg.

[4]Trace menieral mix provides the following (per kg of diet): manganese ($MnSO_4 \cdot H_2O$), 60 mg; iron ($FeSO_4 \cdot 7H_2O$), 30 mg; zinc (ZnO), 50 mg; copper ($CuSO_4 \cdot 5H_2O$), 5 mg; iodine (ethylene diamine dihydroiodide), 1.5 mg; selenium (Na_2SeO_3) 0.13 mg.

[5]Contributed 27.5 mg of bactracin methylene disalicylate/kg.

[6]Coban 60, Elanco Animal Health, Indianapolis, IN.

Statistical Analysis

Data from all chick experiments were initially analyzed using the ANOVA procedure of SAS software (SAS Institute, 1990) for completely randomized designs. Statistical significances of differences among individual treatments were assessed using the least significant difference test (Carmer and Walker, 1985). The relative bioavailabilities of Lys and P were calculated using slope-ratio methodology (Finney, 1978). Multiple regressions were computed with milligrams of supplemental digestible Lys and P intakes from L-

TABLE 4. Determination of Lys availability in DDGS[1] using a slope-ratio bioassay, experiments 2 and 3[2]

Treatment	Body weight gain (g/chick)	Gain:Feed (g:kg)
Experiment 2[3]		
Basal (0.40% available Lys)	15.7[d]	144.8[e]
Basal + 0.10% L-Lys[4]	37.4[c]	270.8[c]
Basal + 0.20% L-Lys	62.0[a]	378.5[a]
Basal + 10% DDGS	30.0[c]	231.7[d]
Basal + 20% DDGS	46.8[b]	334.0[b]
Pooled SEM	2.77	12.8
Experiment 3[5]		
Basal (0.60% avail. Lys)	116.1[c]	505.9[d]
Basal + 0.10% L-Lys	141.3[b]	578.5[b]
Basal + 0.20% L-Lys	186.0[a]	641.3[a]
Basal + 10% DDGS	146.1[b]	546.5[c]
Basal + 20% DDGS	175.1[a]	601.6[b]
Pooled SEM	5.81	8.10

[a-d]Means within a column and experiment with no common superscript differ significantly ($P < 0.05$).

[1]Distillers dried grains with solubles.

[2]Means represent 6 pens per treatment, 6 chicks per pen.

[3]Multiple linear regression of weight gain (Y in g) as a function of supplemental Lys intake (mg) from L-Lys·HCl (X_1) or DDGS (X_2) was Y = 14.4 + 0.15 Lys intake (mg) + 0.10 DDGS intake (g) ($R^2 = 0.98$).

[4]Lysine added from L-Lys·HCl (79% lysine).

[5]Multiple linear regression of weight gain (Y in g) as a function of supplemental Lys intake (mg) from L-Lys·HCl (X_1) or DDGS (X_2) was Y = 114.7 + 0.12 Lys intake (mg) + 0.10 DDGS intake (g) ($R^2 = 0.85$).

TABLE 5. Determination of phosphorus availability in DDGS[1] using a slope-ratio bioassay, experiment 4 and 5[2]

Treatment	Body weight gain (g/chick)	Tibia ash (%)
Experiment 4[3]		
Corn-SBM[4] basal diet (0.12% nonphytate P)	329.9[c]	24.8[d]
Basal + 0.05% P from K_2HPO_4	425.3[b]	28.9[b]
Basal + 0.10% P from K_2HPO_4	498.4[a]	32.7[a]
Basal + 5% DDGS	386.6[b]	26.5[cd]
Basal + 10% DDGS	409.1[b]	27.4[bc]
Pooled SEM	12.7	0.61
Experiment 5[5]		
Corn-SBM basal diet (0.12% nonphytate P)	471.7[b]	25.2[d]
Basal + 0.05% P from K_2HPO_4	504.7[b]	31.1[b]
Basal + 0.10% P from K_2HPO_4	546.1[a]	34.4[a]
Basal + 7% DDGS	497.4[b]	29.0[c]
Basal + 14% DDGS	585.8[a]	30.1[bc]
Pooled SEM	13.8	0.58

[a–d]Means with a column and experiment with no common superscript differ significantly ($P < 0.05$).

[1]Distillers dried grains with solubles.

[2]Means represent 6 pens per treatment, 6 chicks per pen.

[3]Multiple linear regression of tibia ash (Y in %) on supplemental P intake (mg) from K_2HPO_4 (X_1) or DDGS (X_2) was Y = 25.09 + 0.01 P intake (mg) + 0.005DDGS intake (g) ($R^2 = 0.81$).

[4]Soybean meal.

[5]Multiple linear regression of tibia ash (Y in %) on supplemental P intake (mg) from K_2HPO_4 (X_1) or DDGS (X_2) was: Y = 26.11 + 0.01 P intake (mg) + 0.004 DDGS intake (g) ($R^2 = 0.88$).

Lys·HCl or K_2HPO_4 (standards) and DDGS as the independent variables and total body weight gain, feed efficiency, and tibia bone ash (%) as the dependent variable. The digestibilities of L-Lys·HCl (Chung and Baker, 1992; Zhang and Parsons, 1993) and K_2HPO_4 were assumed to be 100%. The calculated ratio of the slope of the DDGS response lines to the L-Lys·HCl or P (K_2HPO_4) standard lines yielded the relative bioavailability estimate for Lys and P, which was then expressed as a proportion of total Lys or P in the DDGS to estimate availability. Prior to computing the multiple regression equations, all response lines were tested for linearity and intersection effects as described by Finney (1978). After the multiple regression coefficients or slopes were tested for statistical differences as outlined by Steel and Torrie (1980), the slope values were then tested for statistical differences as outlined by Finney (1978). All data were analyzed using algorithms generated by SAS Institute (1990).

RESULTS AND DISCUSSION

Experiment 1, 2, and 3; Lys Bioavailability

The total fecal collection assay using adult cecectomized roosters yielded a true digestibility estimate of 75% for the Lys in DDGS. The growth performance and feed efficiency (gain: feed) results for experiments 2 and 3 are summarized in Table 4. A linear growth response ($P < 0.05$) was observed from the addition of supplemental L-Lys·HCl and DDGS to the basal diets in both experiments. Multiple regression methodology was used in both experiments. The equation developed for experiment 2 based on gain was gain (g) = 14.4 + 0.15 Lys intake (mg) + 0.10 DDGS intake (g); $R^2 = 0.98$. The relative bioavailability of Lys was then estimated using the slope-ratio methodology in which body weight gain was regressed on Lys intake from L-Lys·HCl and DDGS. The ratio of slopes indicated a relative bioavailable Lys concentration of 0.67% in DDGS. The determination of available Lys in DDGS was calculated by dividing the relative bioavailability value, which was determined by slope-ratio, by the total Lys concentration value (0.83%) to yield an availability estimate of 80%. In experiment 3, the model developed was gain (g) = 114.7 + 0.12 Lys intake (mg) + 0.10 DDGS intake (g); $R^2 = 0.85$. The ratio of slopes indicated a relative bioavailability Lys concentration of 0.83% in DDGS. This value expressed as a percentage of 0.83% total Lys in DDGS yielded an availability estimate of 100%.

Values obtained based on the chick growth assays varied between experiments 2 and 3. When the multiple regression model was graphed there was an overlap of the standard and test (DDGS) curves, which confirmed the 100% availability of Lys estimated for experiment 3. However, it is unlikely for a nutrient to be 100% available, and this value was deemed questionable. The 80% available Lys determined in experiment 2 was felt to be the more accurate estimated value and was similar to the 75% true Lys digestibility findings in experiment 1.

The Lys bioavailability estimate of 80% obtained with the chick growth experiment was similar and slightly

higher than the reported average Lys digestibility of 71% based on 4 DDGS samples (Ergul et al., 2003). Combs and Bossard (1969) observed similar values of 74 to 90% bioavailable Lys even though the DDGS used was a by-product of the beverage industry. However, Parsons et al. (1983) also conducted a chick growth study using DDGS from the beverage industry and observed a lower Lys bioavailability value of 66%. The Lys digestibility of DDGS (75 to 80%) from modern nonbeverage ethanol plants is higher than reported values from past experiments using DDGS fermented with several grains (Parsons et al., 1983) and the value of 65% reported in the NRC (1994). The results herein indicate that the Lys digestibility of DDGS (75 to 80%) from modern nonbeverage ethanol plants is not extremely different from the Lys digestibility of corn (81%). Thus, the Lys digestibility of DDGS from modern nonbeverage ethanol plants does not appear to be greatly hindered during the drying process.

Experiment 4 and 5; P Bioavailability

The results of the growth performance and tibia bone ash (%) for experiments 4 and 5 are summarized in Table 5. Addition of P at 0.05 and 0.10% from K_2HPO_4 to the basal diet resulted in a linear growth and tibia bone ash (%) response ($P < 0.05$) for both experiments. Addition of DDGS to the basal diets at 5 and 10% for experiment 4 and at 7 and 14% for experiment 5 also resulted in a linear increase in growth and tibia bone ash (%) ($P < 0.05$). A significant difference ($P < 0.05$) was observed between the various levels of P that were supplemented to the basal diet in either form of K_2HPO_4 and DDGS. The results were tested for linearity, and a multiple regression analysis was performed to develop the following models. In experiment 4, the model was tibia ash (%) = 25.09 + 0.01 P intake (mg) + 0.005 DDGS intake (g); $R^2 = 0.81$ and experiment 5 using tibia ash (%) = 26.11 + 0.01 P intake (mg) + 0.004 DDGS intake (g); $R^2 = 0.88$. Using slope ratio methodology the relative bioavailabilities of P based on tibia bone ash (%) for experiments 4 and 5 were 0.50 and 0.40%, respectively. Phosphorus availability was calculated to be 68% for experiment 4 and 54% for experiment 5 based on the total P value of 0.74% in DDGS.

The P bioavailability estimate of 68 and 54% for experiments 4 and 5 is similar to the average value (54%) reported by Martinez Amezcua et al. (2004) for 22 DDGS samples from various nonbeverage ethanol plants in Minnesota. Martinez Amezcua et al. (2004) reported a range of estimated P availability (relative to KH_2PO_4) from 69 to 102%. Working with swine, Whitney et al. (2001) reported higher P availability values of DDGS ranging from 87.5 to 92.2%. The calculated 64% available P (based on total and phytate P%) in DDGS (Table 6) was similar to our findings based on tibia bone ash (%) (61%, average of experiments 4 and 5) and appeared to be much higher than the P availability value extrapolated for corn (29%) based on the NRC (1994) table values (Table 6). Thus, it could be speculated that the fermentation process, which the corn undergoes, improves P availability in the by-product, DDGS, possibly through the synthesis of microbial phytase.

TABLE 6. Percentage of phytate P in DDGS[1]

Feed ingredient	% Total P	% Phytate P	% Available P
Corn (NRC, 1994)[2]	0.28	0.20	29
DDGS[3]	0.74	0.27	64

[1]Distillers dried grains with solubles.

[2]Values obatined from the NRC (1994) and % available P was extrapolated from these values.

[3]Average of 9 DDGS samples.

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