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NUTRITIONAL VALUE OF CONVENTIONAL AND MODIFIED DDGS FOR POULTRY

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Summary

Several experiments were conducted to evaluate the variation in nutrient content and digestibility among different commercial samples of DDGS, the effects of different processing methods and feed additives on the bioavailability of P in DDGS and the effect of new processing technologies on the nutritional value of DDGS for poultry. The nutrient composition varied substantially among DDGS samples, with the greatest variation being found for Ca and Na content and digestibility of lysine. The mean TME content for 20 samples of DDGS was similar to the NRC (1994) table value. The mean bioavailability coefficient for P in 9 samples of DDGS was 79% and varied from 62 to 102%. Bioavailability of P was increased by additional heat processing but protein quality was reduced, particularly lysine digestibility. Particle size had no effect on P bioavailability whereas both phytase enzyme and citric acid increased P bioavailability. Two new processing technologies, modified dry grind and quick germ quick fiber (for removing germ and fiber) increased the protein and reduced the fat and fiber in DDGS and had varying effects on the lysine content. An elusieve process, sieving and air aspiration, reduced the fiber and increased the protein and fat in DDGS. The three new processing technologies generally had no effect on digestibility of amino acids in DDGS. Finally, a commercial sample of high-protein DDGS and corn germ meal were evaluated. Total P in the high-protein DDGS and corn germ meal was .33 and 1.22%, respectively, and bioavailability of the P in the 2 samples were 58 and 25%, respectively. The total Lys as a % of CP was approximately two times greater for corn germ meal than the high-protein DDGS and the amino acid digestibilities were also higher for the corn germ meal, particularly for Lys.

Introduction

Distillers Dried Grains with Solubles (DDGS) is a corn co-product obtained after fermentation of corn for ethanol production. Ethanol from grains is a relatively clean and renewable source of energy. The interest in this fuel to reduce oil consumption has resulted in recent Renewable Fuels legislation that is resulting in a great amount of investment in research and facilities to produce ethanol in the future. Thus, ethanol production is growing in the U.S. and is expected to increase greatly in the future. Most of this increase in ethanol production capacity is expected to come from new dry grind corn plants. This increase in ethanol production will result in an excess of DDGS that will likely provide producers a less expensive and possibly a better quality DDGS. It is important to reevaluate the content of nutrients, availability and variation in digestibility of some nutrients in DDGS for poultry. It is also important to evaluate the possible impact of new processing conditions on the nutritional quality of DDGS. This paper will summarize some of our research on DDGS during the last two years with an emphasis on phosphorus (P) and amino acid bioavailability or digestibility and the impact of new processing methods.

Nutrient Composition and Variation among DDGS Samples

My research group has evaluated approximately 90 samples of DDGS during the last two years for amino acid digestibility using the precision-fed cecectomized rooster assay. Many of these samples have also been evaluated for nutrient content and P bioavailability. The results for one set of 20 representative samples are shown in Table 1. These samples were mostly obtained from feed mills in Minnesota that were supplying feed primarily for poultry operations. The dry matter, fat, ash, and P content of the samples were reasonably consistent. The Ca and Na contents were more variable. Batal and Dale (2003) also reported large variability in concentrations of these nutrients among DDGS samples. The levels of amino acids in the samples were in general agreement with those reported by the NRC (1994), with lysine concentrations being more variable among samples than the other amino acids. For amino acid digestibility, the mean digestibility coefficient for lysine was 72% which was the lowest and most variable (largest CV) for all amino acids. The large variation for lysine digestibility is probably due mostly to differences in degree of heat-damage among samples and the production of Maillard reaction products. The mean TME_n content of the 20 DDGS samples was similar to the NRC (1994) value when calculated on the same DM basis.

Table 1. Summary of Selected Nutrients, TME_n and Amino Acid Digestibility Coefficients for 20 Samples of DDGS

Component (%)	Mean	Range	CV (%)[1]
Dry matter	88	85-89	.9
Fat	14	13-16	4.8
Ash	4	3.7-4.4	5.0
Ca	.03	.02-.04	38.4
P	.73	.62-.77	5.3
Na	.11	.05-.17	32.8
Lysine	.73	.59-.89	11.6
Methionine	.49	.41-.60	9.7
Threonine	.98	.85-1.14	6.0
Cystine	.52	.42-.67	11.3
Lys digest.[2]	72	59-84	11.2
Met digest.	88	85-92	1.9
Thr digest.	76	69-83	4.8
Cystine digest.	77	66-87	7.7
TME_n kcal/kg	2863	2607-3054	3.6

[1]Coefficient of variation.
[2]Amino acid digestibility coefficients determined in cecectomized roosters.

Bioavailability of P in DDGS

We have conducted several experiments to determine bioavailability of P in samples of DDGS using a chick growth-tibia ash assay. The results for one representative assay are shown in Table 2 (Martinez-Amezcua et al., 2004). A P-deficient cornstarch-dextrose-soybean meal diet was formulated to contain 0.10% nonphytate P. This P-deficient diet was then supplemented with .05 or .10% P from KH_2PO_4 or 8 and 16% of three DDGS samples in place of cornstarch and dextrose. A highly linear response was obtained in tibia ash from the KH_2PO_4 and the DDGS samples. Bioavailability of the P in the DDGS relative to KH_2PO_4 was then calculated using multiple linear regression by the slope-ratio method (Table 2, Footnote 4). A summary of P bioavailability values for 9 samples of DDGS from further chick tibia assays from my lab is shown in Table 3. The mean bioavailability coefficient for P was 79% and ranged from 62-102%. Mean bioavailable P content was calculated to be 0.58%. These results indicated that DDGS contains a substantial amount of bioavailable P but that the content and bioavailability varies among samples.

Table 2. Growth from 8 to 21 d of Age and 12 d Tibia Ash for Chicks in a P Bioavailability Assay[1]

Dietary treatment	Weight gain (g)	Tibia ash	
		(mg/chick)[4]	(%)
1. Basal	246[d]	272[d]	34.7[f]
2. B + 0.05% P[2]	272[bc]	349[c]	39.6[bcd]
3. B + 0.10% P[2]	280[bc]	397[b]	41.7[a]
4. B + 8% DDGS 1[3]	273[bc]	348[c]	38.7[cde]
5. B + 16% DDGS 1[3]	293[a]	434[a]	41.9[a]
6. B + 8% DDGS 2[3]	277[bc]	355[c]	38.3[de]
7. B + 16% DDGS 2[3]	282[abc]	389[b]	41.2[ab]
8. B + 8% DDGS 3[3]	270[c]	332[c]	37.5[e]
9. B + 16% DDGS 3[3]	283[ab]	392[b]	40.3[abc]
Pooled SEM	4	10	0.6

[a-d]Means within a column with no common superscript differ significantly ($P < 0.05$).
[1]Means represent four pens of five chicks per treatment; average initial weight was 93.3 g.
[2]From KH_2PO_4
[3]DDGS= distillers dried grains with solubles. The three DDGS samples varied in lysine digestibility. The lysine digestibility coefficients for DDGS 1, 2 and 3 were 64.2, 61.2 and 78.8% respectively, as determined by the precision-fed cecectomized rooster assay.
[4]Multiple regression of tibia ash (Y; mg) on supplemental P intake (g) from KH_2PO_4 (X_1) or DDGS 1, 2 and 3(X_2-X_4, respectively) yielded the equation: $Y = 281 + 282 \pm 29.9X_1 + 289 \pm 24.5X_2 + 231 \pm 25.3X_3 + 212 \pm 24.6X_4$ ($R^2 = 0.84$)

Table 3. Relative Bioavailability of Phosphorus in Nine Samples of Distillers Dried Grains with Solubles (DDGS)

DDGS sample	Bioavailability coefficient[1] (%)	Total P content (%)	Bioavailable P content[2] (%)
1	69	0.72	0.49
2	102	0.74	0.75
3	82	0.72	0.59
4	75	0.73	0.55
5	62	0.67	0.42
6	70	0.76	0.53
7	82	0.72	0.59
8	87	0.77	0.67
9	84	0.74	0.62
Mean	79	0.73	0.58

[1]Bioavailability of the P in DDGS relative to KH_2PO_4. Calculated by the slope-ratio method using the multiple regression.
[2]Calculated by multiplying the bioavailability coefficient by the total P content in the DDGS.

Some previous studies in the literature (Mahgoub and Elhag, 1998; Carlson and Poulson, 2003) have indicated that increased heat processing may increase P bioavailability in some plant ingredients. Therefore, we conducted a series of experiments to determine if increased heat processing would increase the bioavailability of P in DDGS. The increased heat processing treatments consisted of autoclaving for varying amounts of time at 121°C and 124 KPa or by dry oven-heating at 55°C or at 121°C. The results for selected samples are shown in Table 4. Autoclaving for 75-80 min or oven drying at 55°C for 3 days followed by autoclaving for 60 min or oven-drying at 121°C for 60 min resulted in increased bioavailability of P. These results indicated that increased heat processing of DDGS may indeed increase P bioavailability. However, although the increased heating had beneficial effects for P, it also had large negative effects on amino acid digestibility, particularly for lysine (Table 5). Autoclaving or drying reduced the total lysine content of DDGS but had little or no consistent effect on concentration on other amino acids. Digestibility of all amino acids, however, was reduced by autoclaving, with

very large negative effects on lysine digestibility (decreased from 68 to 8%). These results indicate that although increased heating may increase bioavailability of P, the large negative effects on amino acid digestibility make this an enviable economic alternative.

Table 4. Bioavailability of Phosphorus in Distillers Dried Grains with Solubles (DDGS) Heat Processed Under Different Conditions in Two Experiments

DDGS sample[1]	Bioavailable P content (%)	Bioavailability coefficient (%)
Experiment 1:		
Original DDGS	0.57[b]	75[b]
Autoclaved for 75 min	0.67[a]	87[a]
Experiment 2:		
Original DDGS	0.53[b]	70[b]
Autoclaved for 80 min	0.66[a]	86[a]
OV55-A60	0.63[a]	83[a]
OV55-OV121	0.69[a]	91[a]

[a-b]Means within a column and experiment with no common superscript differ significantly ($P < 0.05$).
[1]OV55-A60 = oven dried at 55°C for 3 days and then autoclaved for 60 min; OV55-OV121 = oven dried at 55° C for 3 days then oven dried at 121°C for 60 min.

Table 5. Total Amino Acid Concentrations (%) and Digestibility Coefficients (%) for Selected Samples of Distillers Dried Grains with Solubles (DDGS) Heated Under Different Conditions

	Original DDGS		80 min autoclaving		Oven drying 55 C + 60 min autoclaving[1]		Oven drying 55 C + oven drying 60 min[2]	
Amino acid	Total	Dig.[3]	Total	Dig.[3]	Total	Dig.[3]	Total	Dig.[3]
Thr	1.1	78[a]	1.0	57[b]	0.9	60[b]	1.1	73[a]
Cys	0.5	88[a]	0.4	46[c]	0.4	50[c]	0.5	74[b]
Val	1.4	81[a]	1.3	51[c]	1.2	49[c]	1.2	62[b]
Met	0.5	84[a]	0.4	75[c]	0.5	81[b]	0.5	87[a]
Ile	1.0	83[a]	0.9	66[b]	0.9	63[b]	0.9	79[a]
Leu	3.3	91[a]	3.2	78[c]	3.0	78[c]	3.2	85[b]
Tyr	1.0	90[a]	1.0	78[c]	0.9	79[c]	1.0	83[b]
Phe	1.4	90[a]	1.3	70[c]	1.3	69[c]	1.3	78[b]
His	0.7	80[a]	0.6	64[c]	0.6	63[c]	0.7	78[b]
Lys	0.9	68[a]	0.4	13[c]	0.3	8[c]	0.6	45[b]
Arg	1.2	86[a]	0.8	53[c]	0.9	55[c]	1.1	71[b]
Trp	0.2	81[a]	0.1	62[b]	0.1	45[c]	0.2	81[a]

[a-c]Means within a row with no common superscript are different ($P < 0.05$).
[1]Oven dried at 55°C for 3 days and then autoclaved for 60 min.
[2]Oven dried at 55° C for 3 days and then oven dried at 121° C for 60 min.
[3]Dig. = digestibility coefficient.

An additional series of experiments was conducted to evaluate the effects of particle size on bioavailability of P in DDGS. The results indicated that grinding and feeding DDGS samples ranging in particle size from 542 to 872 um had no effect on P bioavailability.

A final series of experiments were conducted to determine if phytase enzyme and/or citric acid would increase the bioavailability of P in DDGS. Phosphorus deficient diets were formulated which contained 30 to 40% DDGS as the only protein source along with supplemental amino acids. These diets were then supplemented with 1,000 or 10,000 units of phytase per kg of diet (Opti-phos phytase, United Feeds, Sheridan IN) or with KH_2PO_4 as a P standard. The results of the first experiment with phytase only are shown in Table 6. Both 1,000 and 10,000 FTU/kg phytase significantly increased tibia ash, indicating that phytase enzyme can indeed improve bioavailability of P in DDGS. A second experiment with both Opti-phos phytase and 3% citric acid yielded similar results. By calculation comparing the phytase and citric acid responses to the KH_2PO_4 responses in tibia

ash, it was estimated that phytase and citric acid could release from .05-.07% P in DDGS (i.e., make that amount bioavailable). These increases represent approximately 20 to 28% of the non-bioavailable P in DDGS.

Table 6. Growth Performance and Tibia Ash for Chicks Fed a Phosphorus-Deficient Diet Based on Amino Acid-Fortified Distillers Dried Grains with Solubles (DDGS), Experiment 1[1]

Dietary treatment	Weight gain	Feed intake	Gain:feed ratio	Tibia ash	
	(g)	(g)	(g/kg)	(mg/tibia)	(%)
1. Basal diet (40% DDGS) (B)[2]	288[b]	481[a]	599[b]	453[c]	42.1[d]
2. B + 1,000 FTU/kg phytase	297[b]	482[a]	612[ab]	503[b]	43.6[c]
3. B + 10,000 FTU/kg phytase	299[b]	486[a]	621[a]	519[b]	44.4[b]
4. B + 0.9% KH_2PO_4[3]	314[a]	499[a]	631[a]	570[a]	45.5[a]
	5				
Pooled SEM		8	7	8	0.2

[a-c]Means within a column with no common superscript differ significantly ($P < 0.05$) using the LSD test.
[1]Means represent four pens of five chicks per treatment; average initial weight was 93.7 g. Performance data are for the period of 8 to 21-d posthatch.
[2]Analyzed to contain .3% total P and estimated to contain .26% nonphytate P.
[3]Calculated to provide 0.2% supplemental P.

Nutritional Characteristics of DDGS as Affected by Different Processing Techniques

As mentioned earlier, most of the increase in ethanol production in the U.S. is expected to come from dry grind corn plants. Due to the large expected increase in DDGS production, there is an interest to modify processing in dry grind plants and develop new technologies to increase the nutritional value of DDGS and to produce new products for market diversification.

New processing and fractionation technologies are thus being developed for DDGS to recover nonfermentables (germ and fiber) prior to the dry grind process. These technologies include the quick germ quick fiber method (QGQF) (Singh et al., 1999) and a modified dry milling process (Duensing et al., 2003) that recover germ and pericarp fiber at the beginning of the dry grind process prior to fermentation. Another technology, called "elusieve," that removes fiber from DDGS has recently been developed (Radhakrishnan et al., 2005). The elusieve process includes fractionation of DDGS to remove fiber by sieving and air aspiration. We have recently conducted initial studies to evaluate the nutritional value of DDGS produced using these new technologies. A description of the new processes or technologies is presented below.

1. ***Conventional dry grind method***. Conventional dry grind processing was done as described by Singh et al. (2005). A yellow dent corn hybrid grown during the 2002 crop season at the Agricultural Engineering Research Farm, University of Illinois at Urbana-Champaign was used for this study. The hybrid was field dried to approximately 15% moisture content and combine harvested. Corn samples were hand cleaned to remove broken corn and foreign material, packaged in plastic bags and stored at 4°C until processing. Whole kernel moisture content was measured using a 103°C convection oven method (AACC 2000: Method 44-15A).

2. ***Modified dry grind process (MDG)***. A sample of 1000 g corn was tempered to a moisture content of 22.5% for 18-20 min. The tempered corn was passed through a horizontal drum degerminator which impacts and abrades the corn, resulting in partial separation of germ and fiber from endosperm. The product was then dried for two hr at 49°C to approximately 15% moisture. The dried material was processed four times through a roller mill and sieved over a 10 mesh sieve. The germ and fiber fractions which were retained on the sieve were separated by aspiration. The remaining milled fraction was analyzed for moisture (AACC, 2000, Method 44-18), liquefied, and fermented using the conventional dry grind process.

3. ***Quick germ quick fiber process (QGQF).*** The QGQF process was done as outlined by Singh et al. (1999). The modified process involves soaking the ground corn in water with alpha-amylase for 12 hours to increase specific gravity to float germ and fiber prior to fermentation. The QGQF procedure was modified slightly to maintain the specific gravity of the slurry for recovery of germ and fiber. The modifications included

addition of 3 ml of enzyme (alpha-amylase, Bacillus amyloliquefaciens, 1,4-a-D-glucan glucanohydrolase, 9000-85-5, MFCD00081319) and incubation of the slurry for 4 hr after soaking and coarse grinding of the corn kernels.

The DDGS samples from the conventional dry grind, MDG and QGQF processes were dried for 3 days at 60°C. The three samples were then tube-fed to four cecectomized roosters in order to estimate TME and amino acid digestibility.

4. ***Elusieve process***. A commercial DDGS sample was obtained from a dry grind corn plant in the U.S. A vibratory screen (Model LS188333, SWECO Vibro-Energy Separator, Los Angeles, CA) and air aspiration were used to fractionate the commercial DDGS sample with a 234 μm sieve as described by Radhakrishnan et al. (2005). The heavier sieved material (material passing through the 234 μm sieve) was collected and called elusieve DDGS. This elusieve DDGS was then tube-fed to four cecectomized roosters to estimate TME_n and amino acid digestibility.

In addition, a commercial sample of new high-protein DDGS and corn germ meal were evaluated in a final study. For the latter, total content and bioavailability of P and also total and digestible amino acids were determined.

The nutrient composition of the DDGS produced using the different processes are shown in Table 7. The DDGS produced by the MDG and QGQF had higher CP and lower fat and fiber than the conventional DDGS. The lower fat was due to the removal of germ. Most of the fiber in DDGS is insoluble dietary fiber. Total P was reduced in MDG. This reduced P in MDG was again due to removal of germ. When comparing amino acid levels expressed as a % of the CP, lysine was reduced in the MDG but not in the QGQF. Again, the reduction in lysine was due to removal of germ. The observation that lysine did not decrease in the QGQF (germ was also removed) suggests that leaching of lysine occurred during the soaking process. The changes in nutrient composition for the elusieve processing were as expected. This process reduced the total dietary fiber greatly and subsequently, the levels of CP and fat increased. The elusieve process had no effect on the amino acid levels expressed as a % of the CP. The results of the precision-fed cecectomized rooster assay indicated that the processing methods had little or no effect on the digestibility of amino acids in DDGS.

Table 7. Composition of Distillers Dried Grains with Solubles (DDGS) Samples Produced by Different Processing Methods

Component[1]	Conventional process in laboratory	Modified dry grind	Quick germ quick fiber	Commercial DDGS	Elusieve DDGS
Dry matter	91	87	78	89	91
CP (%)	21.2	23.8	28.0	31.3	40.8
Fat (%)	13.9	8.7	5.4	11.8	15.0
Ash (%)	4.0	2.8	ND[2]	4.6	ND
Total dietary fiber (%)	36.4	28.0	25.3	34.5	19.7
Insoluble dietary fiber (%)	34.9	26.5	22.5	33.2	18.2
Soluble dietary fiber (%)	1.5	1.5	2.8	1.3	1.5
Total phosphorus (%)	0.78	0.47	ND	0.74	0.9
Lysine[2] (% of CP)	3.4	2.5	3.3	3.2	3.0
Threonine[2] (% of CP)	3.7	3.7	3.4	3.6	3.5
Tryptophan[2] (% of CP)	0.9	0.8	0.8	0.7	0.7

[1]All the components are expressed on a DM basis
[2]ND = not determined

The results for the new commercial high-protein DDGS and corn germ meal are summarized in Table 8. The high protein DDGS contained more protein and Lys and higher bioavailability of P than the corn germ meal whereas the corn germ meal contained more total P, higher Lys as % of protein and higher Lys digestibility.

Table 8. Nutrient Composition and Bioavailability/Digestibility of Some Nutrients (%) in High-Protein DDGS and Corn Germ Meal

Sample	Total P	Bioavailability of P	Protein	Total Lys	Lys as % of Protein	Lys Digestibility
High-protein DDGS	0.33	58	33	.95	2.8	73
Corn germ meal	1.22	25	14	.80	5.7	91

Overall, these results indicate that new processing technologies such as MDG, QGQF, and elusieve will have substantial effects on the nutritional value of DDGS for poultry. The effects may be positive or negative. Certainly, the elusieve process will have positive effects by yielding a lower fiber, higher energy and protein ingredient. The MDG and QGQF will likely have both positive and negative effects. These processes reduce the fiber but also reduce the oil or fat; thus, they may have little net effect on the energy content. The MDG process will likely reduce the protein quality, even though the protein quantity is increased, because of the reduction in lysine. Modified processing of DDGS to produce higher-protein DDGS and corn germ meal will have similar types of variable effects on the nutritional value of the end products. The use of new and diversified technologies by the ethanol industry will result in greater variation in the nutritional composition and value of DDGS produced by different plants. Thus, it will be very important for the end-user of DDGS to be aware of this and to be sure that they have accurate nutritional values for the specific DDGS that they are buying and feeding.

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