Physical, Chemical, and Nutritional Characteristics of Distillers Dried Grains with Solubles for Chicks and Pigs[1,2,3]

G. L. Cromwell[4], K. L. Herkelman[5], and T. S. Stahly[6]

Department of Animal Sciences, University of Kentucky, Lexington 40546

ABSTRACT: The physical characteristics, chemical composition, and nutritional value of distillers dried grains with solubles (DDGS) from seven beverage alcohol and two fuel alcohol manufacturers were evaluated in studies with chicks and pigs. Color scores of the DDGS ranged from very light to very dark and odor scores ranged from normal to burnt or smoky. The DDGS ranged from 23.4 to 28.7% CP, 2.9 to 12.8% fat, 8.8 to 36.9% ADIN, 28.8 to 40.3% NDF, 10.3 to 18.1% ADF, and 3.4 to 7.3% ash. Lysine concentrations of the DDGS ranged from .43 to .89%. In the first experiment, 12 corn-based diets were fed to 1-d-old chicks for 21 d to assess the nutritional value of the DDGS sources. A low-protein basal diet was supplemented with soybean meal to provide 13.6, 16.5, or 19.0% CP or supplemented with 20% DDGS, which supplied approximately the same amount of CP as the highest level of soybean meal. Weight gain, feed intake, and feed/gain were influenced ($P < .01$) by source of DDGS. The weight gain of chicks fed the DDGS sources ranged from 85% of that of chicks fed the highest level of soybean meal to less than that of chicks fed the low-protein basal diet. Blends of the three best sources of DDGS and the three poorest sources of DDGS were evaluated in a subsequent chick trial. The relative nutritional values of the two blends were similar to the average of the sources that made up the blends. Performance responses to various blends of DDGS in the pig experiment paralleled those of the chick trial. Rate and efficiency of gain were correlated with color of the DDGS and concentrations of CP, lysine, S-amino acids, ADIN, and ADF in the DDGS. The results indicate that there is a great amount of variability in the physical, chemical, and nutritional properties among the sources of DDGS that are available to the feed industry.

Key Words: Distillers Grains, Pigs, Chicks

J. Anim. Sci. 1993. 71:679–686

Introduction

Distillers dried grains with solubles (**DDGS**) is a byproduct resulting from the fermentation of cereal grains for the production of alcohol for beverage or fuel. It has long been recognized that DDGS is a valuable source of energy, protein, water-soluble vitamins, and minerals for animals. Some of the early research studies with pigs indicated that distillers dried solubles also provided a source of unidentified growth factors (Catron et al., 1954, 1955; Gage et al., 1961), but later studies failed to show an unidentified growth factor effect from the inclusion of distillers dried solubles in practical swine diets (Conrad, 1961; NCR-42 Committee on Swine Nutrition, 1970). Dietary inclusion of DDGS is normally limited to 5 to 10% in swine and poultry diets; however, up to 20% DDGS can be included, on an isolysine basis, in diets for growing-finishing swine with only a slight (3 to 4%) reduction in growth rate and efficiency of feed utilization (Cromwell and Stahly, 1986).

Various methods are used in the preparation of DDGS. Often, the end product will vary in physical appearance and in chemical composition, depending on the grains used and the processing and drying procedures. Overheating of oilseed meals and animal protein meals causes reduced availability of lysine (Maillard reaction) and partial destruction of cystine and perhaps of other amino acids (Evans and Butts, 1949; Carpenter, 1960; Rios Iriarte and Barnes, 1966; Hancock et al., 1990; Hurrell, 1990; Parsons et al., 1992), and perhaps this also occurs with DDGS.

[1]Journal paper no. 92-5-29 of the Kentucky Agric. Exp. Sta., Lexington.

[2]This research was partially supported by a grant-in-aid from the Distillers Feed Research Council, Des Moines, IA.

[3]Appreciation is extended to Heartland Lysine, Inc., Chicago, IL for performing the amino acid analyses and to L. E. Chase, Cornell University, for performing the ADIN analyses.

[4]To whom correspondence should be addressed.

[5]Present address: Anim. Sci. Dept., Morehead State Univ., Morehead, KY 40351.

[6]Present address: Anim. Sci. Dept., Iowa State Univ., Ames 50011.

Received March 16, 1992.

Accepted November 4, 1992.

Whether processing methods and drying conditions have a minor or major effect on the nutritional value of DDGS is not known.

The objectives of this study were to assess the degree of variability in the physical properties and chemical composition of various sources of DDGS from beverage and fuel alcohol production, to assess the variability in the nutritional value of different sources of DDGS for chicks and pigs, and to establish relationships between the physical properties, chemical composition, and nutritional value of DDGS for nonruminants.

Procedures

Nine sources of DDGS were obtained for this study. Seven sources were DDGS that originated from the production of beverage alcohol and two sources were from manufacturers that produced fuel alcohol from corn. The DDGS sources derived from production of beverage alcohol were provided by the Distillers Feed Research Council, Des Moines, IA, and the specific manufacturers were not known to the investigators. These sources were identified as Sources A through G. The other two sources (Sources H and I) were obtained from fuel-alcohol plants in Kentucky and Ohio.

Physical characteristics (odor and color) of the nine sources of DDGS were assessed by a three-member panel. Color was subjectively scored from 1 to 5; 1 represented a very light color and 5 represented a very dark color. The nine sources also were ranked by the panel from the lightest to the darkest. In addition, the Hunterlab color procedure (McNaughton et al., 1981) was used to assess quantitatively the lightness, redness, and yellowness of the nine samples.

The nine sources were analyzed for DM, CP, ether extract, and ash using standard procedures (AOAC, 1984). The NDF, ADF, and ADIN concentrations were determined by the method of Goering and Van Soest (1970). The samples also were analyzed for amino acids (courtesy of Heartland Lysine, Chicago, IL) by ion-exchange chromatography after acid hydrolysis. Cystine and methionine were protected by performic acid oxidation before hydrolysis. Tryptophan was determined after alkaline hydrolysis.

Chick Experiments. Two experiments were conducted with chicks to assess the nutritional value of the nine sources of DDGS. In both experiments, 1-d-old, broiler-type chicks (males of a female parent line, Hubbard Farms, Statesville, NC) were used. The chicks were housed in batteries (Petersime Incubator, Gettysburgh, OH) and were allowed to consume their diets and water on an ad libitum basis.

Twelve diets were fed in Exp. 1 (Table 1). Diet 1 was a 13.6% CP, corn-soybean meal diet containing 20% of a starch-cellulose (68:32) mixture. The starch-cellulose mixture was calculated to be isoenergetic with DDGS (2,480 kcal of ME/kg; NRC, 1984). Diets 2 and 3 contained 16.5 and 19.0% CP, respectively; additional soybean meal replaced a portion of the starch-cellulose mixture. The higher-protein diet was calculated to be slightly deficient in CP compared with levels listed by NRC (1984). Diets 4 to 12 consisted of the basal diet with one of the nine sources of DDGS replacing the starch-cellulose mixture. These nine diets contained approximately 19% CP. The rationale behind formulating the diets this way was so that each source of DDGS could be directly compared, on a CP basis, with an equivalent amount of soybean meal protein. The amount of corn was held constant in each diet so that it would not be a contributing factor. Each treatment was replicated four times, with eight chicks per pen. The experiment was conducted for 21 d.

Table 1. Composition of diets, % (Exp. 1)[a]

Ingredient	Diet 1	Diet 2	Diet 3	Diets 4 to 12
Corn	46.28	46.28	46.28	46.28
Soybean meal (44% CP)	21.92	28.57	34.24	21.92
Cornstarch-cellulose	20.00	13.35	7.68	—
DDGS (Sources A–I)[b]	—	—	—	20.00
Corn oil	7.10	7.10	7.10	7.10
Dicalcium phosphate	1.85	1.85	1.85	1.85
Limestone	1.35	1.35	1.35	1.35
Salt	.50	.50	.50	.50
Vitamins-minerals-additives[c]	1.00	1.00	1.00	1.00
Calculated analysis				
CP, %	13.6	16.5	19.0	~19.0
ME, kcal/kg	3,160	3,160	3,160	~3,160

[a]Each diet fed to four pen-replicates of eight 1-d-old chicks per pen for 21 d.

[b]Distillers dried grains with solubles.

[c]Provided, per kilogram of diet: vitamin A, 6,600 IU; vitamin D_3, 1,000 ICU; vitamin E, 15 IU; vitamin K as menadione dimethylpyrimidinol bisulfite (menadione activity), 2.0 mg; thiamin, 5.9 mg; riboflavin, 5.4 mg; pantothenic acid, 15 mg; niacin, 41 mg; biotin, .23 mg; folacin, .83 mg; pyridoxine, 4.5 mg; vitamin B_{12}, 14 μg; choline, 1,450 mg; ethoxyquin, 207 mg; Cu, 6 mg; I, .53 mg; Mn, 83 mg; Fe, 120 mg; Zn, 60 mg; Se, .2 mg; and Co, 5 mg.

In Exp. 2, two blends of DDGS were evaluated. One blend was a combination of Sources B, C, and D and the second blend was a combination of Sources A, E, and H. Each blend consisted of equal parts, by weight, of the three sources of DDGS. Diet 1 (Table 2) was a 12% CP, corn-soybean meal diet with 30% cornstarch. Diets 2, 3, and 4 consisted of the basal diet with soybean meal substituted for starch to provide 14.7, 17.4, and 20.1% CP, respectively. Diets 5, 6, and 7 consisted of the basal diet with 10, 20, or 30% DDGS (blend of Sources B, C, and D) replacing cornstarch. These three diets also contained approximately the same levels of CP as Diets 2, 3, and 4, respectively. Diets 8, 9, and 10 were the same as Diets 5, 6, and 7 except that the DDGS blend consisted of Sources A, E, and H. There were four pen-replicates of eight chicks per pen for each treatment, except for Treatment 1

Table 2. Composition of diets, % (Exp. 2)[a]

Ingredient	Diet 1	2	3	4	5	6	7	8	9	10
Corn	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0
Soybean meal (44% CP)	19.0	25.1	31.3	37.4	19.0	19.0	19.0	19.0	19.0	19.0
Cornstarch	30.0	22.2	14.3	6.5	20.0	10.0	—	20.0	10.0	—
DDGS (Sources B,C,D)[b]	—	—	—	—	10.0	20.0	30.0	—	—	—
DDGS (Sources A,E,H)	—	—	—	—	—	—	—	10.0	20.0	30.0
Corn oil	3.0	4.7	6.4	8.1	3.0	3.0	3.0	3.0	3.0	3.0
Dicalcium phosphate	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Limestone	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Salt	.5	.5	.5	.5	.5	.5	.5	.5	.5	.5
Vitamins-minerals[c]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
DL-methionine	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2
Calculated analysis										
CP, %	12.0	14.7	17.4	20.1	14.7	17.5	20.2	14.6	17.2	19.8
ME, kcal/kg	3,225	3,225	3,225	3,225	3,109	2,990	2,873	3,109	2,990	2,873

[a]Each diet fed to four pen-replicates of eight 1-d-old chicks per pen for 14 d.
[b]Distillers dried grains with solubles.
[c]See Table 1, footnote b.

(the basal diet), in which case there were 12 replications. The experimental period was 14 d.

Pig Experiment. This experiment was conducted to evaluate three blends of DDGS for growing pigs. Hampshire-Yorkshire pigs initially averaging 16.0 kg were used in the study. The pigs were randomly allotted to treatments from outcome groups based on weight and sex, with six pen-replicates per treatment and one pig per pen. The pigs were housed in elevated pens (.6 m × 1.2 m) with expanded metal floors in a temperature-regulated building. The pigs were allowed to consume their feed and water on an ad libitum basis.

Six dietary treatments were evaluated (Table 3). Diet 1 was a corn-soybean meal diet containing 23.4% of a dextrose-cornstarch (1:1) mixture. This diet was calculated to contain 8.6% CP. The soybean meal was increased in Diets 2 and 3 (substituted for dextrose-starch) to provide 11.3 and 14% dietary CP. The 14% CP diet was calculated to be slightly deficient in lysine for pigs of this weight classification (NRC, 1988). Diets 4, 5, and 6 consisted of the basal diet with 20%

Table 3. Composition of diets, % (Exp. 3)[a]

Ingredient	Diet 1	2	3	4	5	6
Corn	68.22	68.22	68.22	68.22	68.22	68.22
Soybean meal (48.5% CP)	5.79	11.37	16.93	5.79	5.79	5.79
Cornstarch	11.68	8.89	6.11	1.68	1.68	1.68
Dextrose	11.68	8.89	6.11	1.68	1.68	1.68
DDGS (Sources B,D)[b]	—	—	—	20.00	—	—
DDGS (Sources G,I)	—	—	—	—	20.00	—
DDGS (Sources A,E)	—	—	—	—	—	20.00
Dicalcium phosphate	1.47	1.47	1.47	1.47	1.47	1.47
Limestone	.56	.56	.56	.56	.56	.56
Salt	.40	.40	.40	.40	.40	.40
Vitamins-minerals[c]	.15	.15	.15	.15	.15	.15
Antibiotic[d]	.05	.05	.05	.05	.05	.05
Calculated analysis						
CP, %	8.6	11.3	14.0	13.7	14.1	14.1
ME, kcal/kg	3,379	3,363	3,348	3,313	3,313	3,313

[a]Each diet fed to six individually penned pigs initially averaged 16.0 kg for 28 d.
[b]Distillers dried grains with solubles.
[c]Provided, per kilogram of diet: vitamin A, 6,600 IU; vitamin D_3, 880 ICU; vitamin E, 22.0 IU; vitamin K (menadione activity), 6.4 mg; riboflavin, 8.8 mg; pantothenic acid, 22.0 mg; niacin, 44.0 mg; vitamin B_{12}, 22.0 μg; Fe, 135 mg; Zn, 135 mg; Mn, 45 mg; Cu, 13 mg; I, 1.5 mg; Se, .3 mg; and Co, .23 mg.
[d]Provided 55 mg/kg of chlortetracycline.

DDGS substituted for the dextrose-starch mixture. The blends (1:1 by weight) of DDGS were Sources B and D (Diet 4), G and I (Diet 5), and A and E (Diet 6). These three diets contained approximately the same level of CP (approximately 14%) as the diet with the highest level of soybean meal (Diet 3). The level of corn was held constant in all diets.

Statistical Analysis. The data of each experiment were analyzed by variance procedures (Steel and Torrie, 1980) using the GLM procedure of SAS (1985). Levels of soybean meal in all three experiments and levels of the DDGS blend in Exp. 2 were tested for linearity and nonlinearity. Individual sources or blends of DDGS were compared using a protected *F*-test and the LSD test. Correlations were tested between various physical and chemical characteristics of the DDGS and performance traits. In each experiment, the pen was considered the experimental unit.

Results

Physical Properties of Distillers Dried Grains with Solubles. Table 4 shows the physical characteristics of the nine sources of DDGS. Sources A and F had a slightly burnt odor and Source H had a definite burnt odor. Source E had a definite smoky odor. All the other sources had an odor that was typical of a dried, fermented product such as DDGS. Subjective color scores ranged from 1 (very light) to 5 (very dark). The four samples that had a burnt or smoky odor were darker in color and had subjective scores of 4 or 5.

The Hunterlab color procedure gives a score to a sample based on its lightness or darkness, redness, and yellowness. The Hunterlab L score ranges from 0 (black) to 100 (white). Positive Hunterlab a and b scores indicate redness and yellowness, respectively; higher scores indicated a greater degree of each color. The Hunterlab L scores (Table 4) ranges from 53.2 (lightest, Source B) to 28.9 (darkest, Source F). The ranking of the DDGS sources by the Hunterlab L method essentially duplicated the ranking of the sources by the panel. According to the Hunterlab L scores, the nine sources fell into three main categories, B and D (lightest), C, G, and I (medium), and A, E, F, and H (darkest). Again, this agreed very closely with the subjective scores of the panel. The Hunterlab b (yellowness) scores ranked the nine sources in the same order as the L scores, but the Hunterlab a (redness) scores did not.

Chemical Characteristics of Distillers Dried Grains with Solubles. The DM content of the nine samples averaged 90.5%, with a range of 87.1 to 92.7% (Table 5). The CP ranged from 23.4 to 28.7%, with an overall average of 26.9%, which agrees with the value of 27.0% protein listed by NRC (1988). Source E was considerably lower in CP (23.4%) than any of the others. Ether extract averaged 9.7%, which agrees closely with the value of 9.3% listed by NRC (1988), but the fat content among the sources was quite variable. Most of the samples ranged from 9 to 12% fat, but one sample contained only 2.9% fat. The ADIN, NDF, ADF, and ash contents of the nine sources also varied considerably. Lightness or darkness did not seem to be related to any of these chemical measurements except for ADF and ADIN, in which case increasing darkness was associated with increased ADF ($r = .62$; $P < .10$) and ADIN ($r = .79$; $P < .01$) concentrations.

The indispensable amino acid concentrations of the DDGS sources are shown in Table 6. Lysine concentration was extremely variable, with more than a twofold difference among DDGS sources (.43 to .89%). The

Table 4. Physical characteristics of nine sources of distillers dried grains with solubles

Source[a]	Odor	Color score[b]	Color rank[c]	Hunterlab color score[d]		
				L	a	b
A	Slightly burnt	4	7	29.0	6.5	12.7
B	Normal	1	1	53.2	4.7	21.8
C	Normal	3	4	40.1	7.1	17.3
D	Normal	2	2	51.7	7.1	24.1
E	Smoky	4	8	31.1	6.1	13.1
F	Slightly burnt	5	9	28.9	6.2	12.4
G	Normal	3	5	38.8	6.8	16.5
H	Burnt	4	6	32.1	6.6	13.0
I	Normal	3	3	41.8	6.5	18.8
Avg		3	—	38.5	6.4	16.6

[a]Samples A through G were from beverage alcohol production. Samples H and I were from fuel alcohol production.
[b]1 = very light, 2 = light, 3 = medium, 4 = dark, 5 = very dark.
[c]Rankings = 1 to 9, lightest to darkest.
[d]L = Lightness of sample, 0 = black, 100 = white; The higher the value of a and b, the greater degree of redness and yellowness, respectively.

Table 5. Chemical characteristics of nine sources of distillers dried grains with solubles[a]

Source[bc]	DM, %	CP, %	ADIN, %	NDF, %	ADF, %	Ash, %
A	92.7	27.9	27.1	35.4	15.5	5.2
B	91.8	26.7	8.8	36.1	12.9	3.4
C	90.6	27.0	10.9	33.3	10.3	7.3
D	90.5	28.7	12.0	30.7	10.3	3.7
E	89.9	23.4	36.9	38.5	13.7	6.1
F	90.5	26.7	27.3	34.8	16.6	4.2
G	91.9	27.4	16.0	40.3	15.3	3.4
H	87.1	26.8	36.3	28.8	18.1	5.3
I	89.6	27.4	26.4	38.5	16.4	4.8
Avg	90.5	26.9	22.4	35.1	14.4	4.8

[a]Ether extract values (mean = 9.7%) are not presented in order not to identify the manufacturers (one manufacturer routinely uses a high proportion of grain sorghum vs corn, which results in a low ether extract content of their DDGS). That source analyzed 2.9% and the others ranged from 8.1 to 12.8% ether extract.

[b]Samples A through G were from beverage alcohol production. Samples H and I were from fuel alcohol production.

[c]As-fed basis.

concentrations of the other amino acids also were variable (range of 1.2- to 1.4-fold difference among sources), but not to the same extent as lysine. The average lysine concentration in DDGS (.70%) was the same as that listed by NRC (1988). Average concentrations of methionine (.51 vs .49%) and phenylalanine (1.45 vs 1.47%) were similar to those listed by NRC (1988). Average concentrations of cystine (.53 vs .29%), leucine (3.33 vs 2.21%), arginine (1.06 vs .96%), histidine (.72 vs .64%), threonine (1.01 vs .92%), and tryptophan (.19 vs .17%) were higher than the values listed by NRC (1988), but average concentrations of isoleucine (1.00 vs 1.38%) and valine (1.35 vs 1.48%) were lower.

On average, lysine concentrations tended to be highest in the lightest-colored DDGS (.86%, Sources B and D), intermediate in the medium (.74%, Sources C, G, and I), and lowest in the darkest-colored DDGS (.62%, Sources A, E, F, and H). The correlation between the Hunterlab L score and lysine concentration was .67 ($P < .05$). The four darker sources of DDGS had lower concentrations of arginine (.99 vs 1.12%), cystine (.49 vs .56%), and total S-amino acids (.99 vs 1.09%) than the other five sources, and the Hunterlab L scores were slightly correlated with arginine ($r = .44$; $P < .25$), cystine ($r = .65$; $P < .10$), and total S-amino acid concentrations ($r = .51$; $P < .15$). There seemed to be no pattern between color and concentrations of the other amino acids in the nine sources of DDGS.

The lysine concentration of DDGS decreased as CP concentration decreased. The correlation between CP and lysine was high ($r = .80$; $P < .01$), but this was partially due to Source E's being considerably lower in CP and lysine than the other eight sources of DDGS. When Source E was excluded, the correlation between protein and lysine among the remaining eight sources of DDGS was considerably less ($r = .43$) and not significant ($P > .20$). The low correlation between CP and lysine is characteristic of corn (Reese and Lewis, 1989; NRC-42 Committee on Swine Nutrition, 1992) as well as other cereal grains.

Table 6. Amino acid composition of nine sources of distillers dried grains with solubles

Source[ab]	Lys, %	Met, %	Cys, %	Trp, %	Thr, %	Ile, %	Arg, %	Leu, %	His, %	Phe, %	Val, %
A	.79	.52	.51	.23	1.12	1.06	1.09	3.12	.65	1.49	1.37
B	.89	.53	.61	.18	.91	.98	1.12	3.03	.70	1.34	1.31
C	.68	.53	.52	.22	.98	.86	.99	2.76	.64	1.26	1.18
D	.82	.48	.54	.22	1.16	1.09	1.12	3.98	.76	1.58	1.47
E	.43	.44	.44	.19	.90	.95	.85	3.22	.58	1.45	1.26
F	.65	.50	.54	.16	1.04	1.02	1.06	3.42	.84	1.49	1.38
G	.77	.55	.58	.20	1.09	1.04	1.22	3.27	.78	1.40	1.39
H	.59	.53	.47	.18	1.08	1.09	.99	3.83	.81	1.66	1.43
I	.76	.53	.58	.21	.89	.99	1.16	3.38	.73	1.42	1.38
Avg	.70	.51	.53	.19	1.03	1.00	1.06	3.33	.72	1.45	1.35

[a]Samples A through G were from beverage alcohol production. Samples H and I were from fuel alcohol production.

[b]As-fed basis.

Table 7. Performance of chicks fed nine sources of distillers dried grains with solubles (Exp. 1)[a]

Diet	CP, %	Weight gain, g[bc]	Feed intake, g[bc]	Feed/gain[bc]
Basal	13.5	373	680	1.82
+ Soybean meal	16.3	513	826	1.61
+ Soybean meal	19.0	577	860	1.49
+ Source A	~19.0	390	640	1.64
+ Source B	~19.0	489	778	1.59
+ Source C	~19.0	488	796	1.63
+ Source D	~19.0	477	760	1.59
+ Source E	~19.0	364	631	1.73
+ Source F	~19.0	447	731	1.64
+ Source G	~19.0	422	700	1.66
+ Source H	~19.0	407	701	1.72
+ Source I	~19.0	425	671	1.58
LSD ($P < .05$)	—	54	80	.06

[a]Each mean represents four pen-replicates of eight chicks per pen; 21-d test.
[b]Linear response to level of soybean meal ($P < .01$).
[c]Difference among DDGS sources ($P < .01$).

Chick Experiment 1. Weight gain and feed intake increased linearly ($P < .01$) and feed/gain decreased linearly ($P < .01$) as the level of soybean meal increased in the diet (Table 7). Growth rate differed ($P < .01$) among chicks fed the various source of DDGS, ranging from 488 and 489 g/d for those fed Sources B and C, respectively, to 364 g/d for chicks fed Source E. Gains of chicks fed Sources B or C were approximately 85% as great as those of chicks fed the highest level of soybean meal. Source E (which had a smoky odor and possessed the lowest lysine content) was consumed in the least amount and resulted in the poorest gain and feed/gain of the nine sources tested. In fact, the weight gains of chicks fed Source E were lower than those of chicks fed the low-protein basal diet, which contained no added soybean meal beyond the basal level. On average, chicks fed diets containing DDGS gained more slowly (434 g/d) and required more feed per unit of gain (1.64) than those fed diets in which an equivalent amount of CP was supplied by soybean meal (577 g/d; 1.49 feed/gain).

Chick Experiment 2. The purpose of this experiment was to evaluate two blends of DDGS. Selection of the DDGS sources for the two blends was based on the performance of chicks fed the individual sources of DDGS in Exp. 1, in which Sources B, C, and D (Blend 1) resulted in the greatest weight gains and Sources A, E, and H (Blend 2) resulted in the three lowest weight gains.

The growth rate and feed/gain of chicks improved linearly ($P < .01$) with increasing levels of soybean meal in the diet (Table 8). Improvements in performance also occurred ($P < .01$) with increasing dietary additions of DDGS, but the improvements were less than for soybean meal additions. The blend of Sources B, C, and D was clearly superior ($P < .01$) to the blend of Sources A, E, and H in terms of chick growth rate, feed intake, and feed efficiency.

Pig Experiment. The purpose of this experiment was to determine whether the relative nutritional values for the DDGS sources obtained in the chick experiment would also apply to pigs. The three blends of DDGS tested in this experiment represented two each of the best (Sources B and D), average (Sources G and I), and poorest (Sources A and E) sources of DDGS, based on the results of the chick tests.

Growth rate and feed/gain of pigs improved linearly ($P < .01$) with increasing level of soybean meal in the diet (Table 9). There were differences ($P < .05$) in gain, feed intake, and feed/gain among the three

Table 8. Performance of chicks fed two blends (three sources/blend) of distillers dried grains with solubles (Exp. 2)[a]

Diet	CP, %	Weight gain, g[bcde]	Feed intake, g[bcde]	Feed/gain[bcde]
Corn-soybean meal	12.0	175	316	1.81
	14.7	261	399	1.53
	17.4	309	408	1.33
	20.1	330	402	1.22
DDGS Sources B,C,D	14.6	200	336	1.68
	17.2	213	344	1.61
	19.8	244	380	1.56
DDGS Sources A,E,H	14.7	180	313	1.74
	17.5	174	297	1.72
	20.2	188	315	1.68
LSD ($P < .05$)	—	20	29	.04

[a]Each mean represents four pen-replicates of eight chicks per pen; 14-d test.
[b]Linear response to level of soybean meal ($P < .01$).
[c]Quadratic response to level of DDGS B,C,D ($P < .01$).
[d]Linear and quadratic responses to level of DDGS A,E,H ($P < .01$).
[e]Difference between DDGS blends ($P < .01$).

Table 9. Performance of pigs fed three blends (two sources/blend) of distillers dried grains with solubles (Exp. 3)[a]

Diet	CP, %	Daily gain, g[bc]	Daily feed, g[bc]	Feed/gain[bc]
Corn-soybean meal	8.6	250	1,239	5.05
Corn-soybean meal	11.3	436	1,566	3.58
Corn-soybean meal	14.0	599	1,562	2.60
DDGS Sources B,D	~14.0	390	1,416	3.61
DDGS Sources G,I	~14.0	291	1,312	4.52
DDGS Sources A,E	~14.0	218	1,103	5.05
LSD ($P < .05$)	—	85	257	.96

[a]Each mean represents six individually penned pigs initially averaging 16.0 kg; 28-d test.
[b]Linear response to level of soybean meal ($P < .01$).
[c]Difference among blends of DDGS ($P < .01$).

Table 10. Correlations of physical and chemical properties of distillers dried grains with solubles with performance of chicks

Item	Weight gain	Feed/gain
Physical properties		
Color score	.63[a]	.60[a]
Hunterlab L	.74[b]	.69[b]
Hunterlab a	.09	.11
Hunterlab b	.72[b]	.74[b]
Chemical properties		
CP	.51	.67[b]
ADIN	.86[c]	.72[b]
Ether extract	.32	.07
NDF	.31	.07
ADF	.59[a]	.38
Ash	.22	.40
Lysine	.62[a]	.85[c]
Cystine	.62[a]	.81[c]
Methionine + cystine	.57[a]	.70[b]

[a]Correlation significant ($P < .10$).
[b]Correlation significant ($P < .05$).
[c]Correlation significant ($P < .01$).

blends of DDGS; the order was the same as that predicted from the chick data.

Correlation of Physical and Chemical Properties with Performance. Table 10 shows the correlations of color and chemical properties of DDGS with weight gain and feed/gain of chicks fed the nine sources of DDGS. These data are based on the results of the first chick experiment because blends (and not individual sources) of DDGS sources were used in the other experiments. Subjective color score and Hunterlab L (lightness/darkness) and b (yellowness) scores were highly correlated with growth rate and feed/gain, whereas Hunterlab a (redness) scores were poorly correlated. Crude protein, lysine, cystine, and total S-amino acid concentrations of the DDGS were highly correlated with feed efficiency and moderately correlated with growth rate. The ADIN concentrations were highly correlated with both gain and feed/gain. The ADF concentrations of the DDGS were more highly correlated with performance than were NDF concentrations. Percentages of ash and fat in the DDGS sources were not closely associated with performance.

Discussion

The results of this research indicate that there is a high degree of variability in the physical, chemical, and nutritional properties among sources of DDGS that are available to the feed industry. Physical appearance (color) was highly related to nutritional properties of DDGS in our study, in that dark-colored DDGS was lower in nutritional value than light-colored DDGS. Those DDGS sources with dark color had a burnt or smoky odor, indicating that the color probably was caused from overheating of the DDGS during the drying process. The higher ADIN values in the darker-colored DDGS also are suggestive of greater heat damage. Overheating of soybean meal, fish meal, and milk products reduces their nutritional value because of binding of lysine (Maillard reaction) and partial destruction of cystine and certain other amino acids (Evans and Butts, 1949; Carpenter, 1960; Rios Iriarte and Barnes, 1966; McNaughton and Reece, 1980). Hancock et al. (1990) and Parsons et al. (1992) recently reported that the analyzed lysine concentration in soybean meal was reduced by overheating. They attributed this to the formation of advanced Maillard reaction products (Hurrell, 1990), in which some of the lysine is not released during acid hydrolysis. The low analyzed lysine concentrations in the darker-colored DDGS sources suggest that these processes may also have occurred with overheating of DDGS.

The DDGS in our study were variable in CP (23.4 to 28.7%), but even more pronounced was the variability in lysine concentration (.43 to .89%). Other amino acids also were somewhat variable (1.2- to 1.4-fold differences), but the degree of variability was less than that for lysine (2.1-fold difference). Lysine, arginine, and cystine concentrations were related to color, but concentrations of other indispensable amino acids were not, suggesting that lysine, arginine, and cystine were more sensitive to overheating than were the other amino acids. Lysine and S-amino acid concentrations in the DDGS were highly predictive of chick and pig performance. This is not surprising, because the basal diets for both chicks and pigs were marginal in CP, thus marginal in lysine, the first-limiting amino acid for pigs (NRC, 1988), and in methionine and lysine, the first- and second-limiting amino acids for chicks (NRC, 1984). The DDGS sources also were quite variable in their fat (2.9 to 12.8%), fiber (28.8 to 40.3% NDF; 10.3 to 18.1% ADF), and ash (3.4 to 7.3%) concentrations, but only ADF seemed to be related to nutritional value. The relationship of increased ADF concentration of DDGS with reduced chick performance is plausible, because ADF is associated with the more indigestible components of feed (Goering and Van Soest, 1970; NRC, 1988).

Considerably greater amounts of spent grains are likely to be available in the future as more grains are used in the production of ethanol for fuel. Processing and drying of these byproducts are not as carefully controlled as they are in the beverage industry. Of the two fuel-alcohol DDGS sources tested, one seemed to be overheated (burnt odor, dark color) and one was not. The nutritional value of these two sources fell within the range of the DDGS sources that originated from beverage alcohol production. Although only two sources of fuel alcohol-derived DDGS were tested, the results imply that the nutritional properties of this type of DDGS are not greatly different from those of beverage alcohol-derived DDGS.

Finally, the consistency of the results obtained from the chick and pig trials indicates that chicks can serve as a useful model in predicting the nutritional value of DDGS for pigs.

Implications

There is considerable variability in the nutritional value of sources of distillers dried grains with solubles (DDGS) that are available to the feed industry. Odor and color seem to be important in determining the nutritional value of DDGS for nonruminants; light-colored DDGS, free from burnt or smoky odor, are more likely to have good nutritional properties. The nutritional value of DDGS is related to its lysine content and is more closely related to acid detergent fiber and acid detergent insoluble nitrogen than to neutral detergent fiber content. The nutritional value of DDGS from fuel alcohol production seems to be similar to that from beverage alcohol production.

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