A Protein Quality Assessment of Wheat and Corn Distillers' Dried Grains with Solubles

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ABSTRACT

The protein quality of distillers' dried grains with solubles (DDGS) made from either soft white winter wheat, hard red wheat, or corn was assessed by amino acid analysis, protein efficiency ratio (PER), and net protein retention bioassays. The amino acid profiles of the whole grain flours and DDGS were similar, indicating that the amino acid profiles of the whole grains were retained throughout the fermentation process. Chemical scores of DDGS revealed that lysine was the most limiting amino acid. Both the PER and net protein retention assays ranked the different types of DDGS in the same order. The PER was < 1.0 for DDGS. The in vitro protein digestibilities of red wheat DDGS and white wheat DDGS were significantly lower than in the unconverted whole grains. The much improved growth rates and food intake of rats fed a diet containing supplemental crystalline amino acids added to the white wheat DDGS basal diet indicated that the main reason for retarded growth in rats fed DDGS as a sole protein source was deficient intake of essential amino acids.

Distillers' dried grains with solubles (DDGS) are the major by-product in the fermentation of whole grains to ethanol. DDGS are made by drying the solid residue remaining after enzymatic treatment and yeast fermentation of whole grains. Currently, DDGS produced from cereal grains are sold as animal feed; however, DDGS produced from whole wheat have shown promise as an ingredient in food products. Wheat DDGS are high in dietary fiber (Dong and Rasco 1987) and in protein (Rasco et al 1987a). Baked goods containing wheat DDGS have been rated favorably by consumer panels (Rasco et al 1987b).

The purpose of this study was to assess the protein quality of wheat DDGS and corn DDGS using both in vivo and in vitro methods: amino acid analyses, the protein efficiency ratio, and net protein retention bioassays, and in vivo and in vitro measurements of protein digestibility.

MATERIALS AND METHODS

DDGS were prepared as previously described (Rasco et al 1987a) from the 1985 crops of soft white winter wheat (Hill 81 cultivar), red wheat (grade no. 1 baker's blend of two-thirds Weston, a variety of hard red winter wheat, and one-third hard red spring wheat from the varieties Fremont, Pilot, or Bannock), and corn (grade no. 1 yellow dent). All whole grains and DDGS were ground in an Alpine pin mill, with 100% passing through a U.S. standard no. 16 sieve.

Amino Acid Analysis

Amino acid analyses were performed on Animal Nutrition Research Council (ANRC) reference casein (Teklab Diets, Madison, WI), whole soft white wheat and white wheat DDGS, whole red wheat and red wheat DDGS, and corn and corn DDGS using a Dionex model D-500 amino acid analyzer (Dionex Corp., Sunnyvale, CA). A 20-hr, 6*N* HCl hydrolysis was performed at 115°C. Tryptophan was measured after a 48-hr alkaline hydrolysis at 135°C (Hugli and Moore 1972). Lysinoalanine was measured using lithium eluents (Pickering 1978).

Chemical Scores

Chemical scores were calculated by dividing the concentration of amino acid in the grain or DDGS by the essential amino acid scoring pattern (NAS 1980).

Protein Efficiency Ratio and Net Protein Retention Assays

The protein efficiency ratio (PER), a 28-day assay, was measured according to the AOAC procedure 43.2531 (AOAC 1984). Net protein retention (NPR), a 14-day test, was performed as described by Bender and Doell (1957).

Before the rat diets were prepared, ANRC reference casein, white wheat DDGS, red wheat DDGS, and corn DDGS were subjected to proximate analyses using the following methods (AOAC 1984): nitrogen (14.026), lipid (14.018), ash (14.006), crude fiber (7.071), and moisture (14.004). Neutral detergent fiber (NDF) was assayed with sodium sulfite in detergent solution as previously described (Dong and Rasco 1987, Goering and Van Soest 1970, McQueen and Nicholson 1979).

Diet Formulation

The proximate analysis data (Table I) were used to calculate the formulas (AOAC 1984) for the control and test diets (Table II). Two adjustments were made to the fiber component of the diet. NDF was used instead of crude fiber to calculate the fiber content of the diet because DDGS are rich in fiber, and NDF is more representative of total dietary fiber than is crude fiber (Dong and Rasco 1987, San Buenaventura et al 1987). Also, the total fiber content of the diet was increased from 1 to 8%, and the digestible carbohydrate was decreased from 70 to 63% to accommodate the high fiber level in DDGS. Proximate analyses, using the methods cited previously, were performed on the prepared diets to ensure uniformity in nutrient content.

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TABLE I
Proximate Composition of Protein Sources (% wet weight basis)[a]

Protein Source[b]	Nitrogen	Lipid	Ash	Crude Fiber	Neutral Detergent Fiber	H_2O
ANRC reference casein[c]	13.32 ± 0.43	0.2 ± 0.1	1.1 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	7.2 ± 0.0
White wheat DDGS	6.47 ± 0.21	3.2 ± 0.2	5.4 ± 0.0	7.3 ± 0.4	29.2 ± 7.0	8.0 ± 0.6
Red wheat DDGS	5.50 ± 0.41	3.4 ± 0.2	5.1 ± 0.1	6.8 ± 0.2	25.9 ± 0.3	5.7 ± 0.6
Corn DDGS	5.05 ± 0.57	8.9 ± 0.1	4.1 ± 0.1	5.7 ± 0.2	25.0 ± 2.9	9.7 ± 0.4

[a] Mean ± SD ($n = 3$). Nitrogen, lipid, ash, crude fiber, and H_2O were measured as described in AOAC (1984). Neutral detergent was assayed with sodium sulfite in the detergent solution (Dong and Rasco 1987).
[b] Preparation of distillers' dried grains with solubles (DDGS) is described in Rasco et al (1987a).
[c] Teklab Diets, Madison, WI.

TABLE II
Composition of Diets with or without Distillers' Dried Grains with Solubles (DDGS) (g/100 g of diet)

Ingredient	ANRC Reference Casein	White Wheat DDGS	Red Wheat DDGS	Corn DDGS	Essential Amino Acid Fortified White Wheat DDGS	Zero Protein
ANRC reference casein[a]	12.01	···	···	···	···	···
DDGS[b] from white wheat, red wheat, or corn	···	24.73	29.09	31.68	24.73	···
Corn oil[c]	7.98	7.21	7.01	5.18	7.21	8.00
Cornstarch[d]	31.80	29.40	25.37	26.23	27.85	42.80
Dextrose[d]	30.00	30.00	30.00	30.00	30.00	30.00
AIN mineral mixture 76[e]	4.87	3.66	3.52	3.70	3.66	5.00
AIN vitamin mixture 76A[e]	1.00	1.00	1.00	1.00	1.00	1.00
Nonnutritive fiber[a] (cellulose type)	8.00	0.78	0.47	0.08	0.78	8.00
H_2O (distilled)	4.14	3.02	3.34	1.93	3.02	5.00
Choline bitartrate[a]	0.20	0.20	0.20	0.20	0.20	0.20
Essential amino acids[f]	···	···	···	···	1.55	···

[a] Teklab Diets, Madison, WI.
[b] Prepared as previously described (Rasco et al 1987a).
[c] Mazola, Best Foods, CPC International, Inc., Englewood Cliffs, NJ.
[d] Corn Products, Englewood Cliffs, NJ.
[e] ICN Nutritional Biochemicals, Cleveland, OH.
[f] DL-Met, 168 mg; L-leu, 142 mg; DL-val, 270 mg; L-lys $(HCl)_2$, 756 mg; L-thr, 114 mg; L-trp, 3 mg; L-isl, 101 mg; ICN Nutritional Biochemicals.

TABLE III
Amino Acid Composition of Casein, White Wheat, Red Wheat, Corn, and Distillers' Dried Grains with Solubles (DDGS) (g amino acid/16 g N)[a]

Amino Acid	Reference Casein	White Wheat	White Wheat DDGS	Red Wheat	Red Wheat DDGS	Corn	Corn DDGS	Essential Amino Acid Scoring Pattern[b]
Alanine	2.85	3.76	3.97	3.59	3.82	7.92	7.74	···
Arginine	3.86	4.96	5.59	4.96	4.82	4.08	4.36	···
Aspartic acid	6.78	5.75	5.70	5.04	5.06	5.80	5.60	···
Cystine/2[c]	0.29	2.11	2.49	2.28	2.20	2.32	2.02	2.6 (Met + Cys)
Glutamic acid	21.49	30.69	29.44	32.00	29.88	18.74	18.03	···
Glycine	1.76	4.14	4.45	3.98	4.32	3.93	3.99	···
Histidine	2.89	2.55	2.66	2.45	2.42	2.96	2.89	1.7
Isoleucine	4.87	3.55	3.86	3.60	3.70	3.58	3.85	4.2
Leucine	9.03	6.92	7.61	6.93	7.07	13.40	13.50	7.0
Lysine	7.86	2.95	2.81	2.79	2.46	2.82	2.26	5.1
Methionine	2.37	1.26	1.53[d]	1.26	1.96[d]	1.62	2.00[d]	2.6 (Met + Cys)
Phenylalanine	5.01	4.63	5.22	4.78	4.79	5.11	5.21	7.3 (Phe + Tyr)
Proline	8.53	10.34	9.89	9.77	10.18	9.47	8.93	···
Serine	5.59	4.98	4.93	4.98	5.03	5.16	5.34	···
Threonine	4.10	2.99	2.96	2.92	3.02	3.69	3.92	3.5
Tryptophan[e]	1.10	1.01	1.07	0.90	0.89	0.49	0.64	1.1
Tyrosine	5.49	3.23	3.46	3.35	3.34	4.08	4.57	7.3 (Phe + Tyr)
Valine	6.39	4.45	5.04	4.25	4.94	4.80	5.04	4.8
Lysinoalanine[f] (% w/w)	ND[g]	<0.04	<0.04	<0.04	<0.04	ND	ND	···

[a] DDGS prepared as previously described (Rased et al 1987a). Complete description of grains is given in Materials and Methods. 20-hr 6 *N*-HCl hydrolysis at 115°C except as noted. One crystal of phenol added before acid hydrolysis. Serine increased by 10% and threonine increased by 5% to compensate for destruction by acid. Calculations based on total amino acid recovery.
[b] NAS (1980).
[c] Performic acid oxidized prior to acid hydrolysis. Calculated from cysteic/alanine ratio.
[d] Methionine + methionine sulfone.
[e] Determined by 48-hr alkaline hydrolysis at 135°C; method of Hugli and Moore (1972).
[f] Analyzed with lithium eluents (Pickering 1978).
[g] Not determined.

Experimental Design

Sixty-six male, weanling Sprague Dawley rats (Tyler Laboratory, Bellevue, WA) were placed in individual stainless steel, screen-bottom cages in a room maintained at 24–25° C with a 12-hr light-dark cycle. Food and water were provided ad libitum. Food was placed in metabolic feeding cups (Hazelton Systems, Inc., Aberdeen, MD).

Initially, during a three-day acclimation period, the rats were fed the standard PER diet (AOAC 1984) containing "high-protein casein" (Teklab Diets, Madison, WI) as the protein source. The animals were assembled in groups of 11. The mean weight and standard deviation of the 6 groups was 55.3 ± 0.7 g. Each group was fed one of the six diets (Table II) containing the following protein sources: ANRC reference casein (RC), white wheat DDGS (WW), red wheat DDGS (RW), corn DDGS (CO), amino acid-fortified white wheat DDGS (FWW), and zero protein (ZP). Food consumption, taking spillage into account, was recorded when fresh diet was placed in the food cups twice per week. Rats were weighed and water was changed at least once per week.

The FWW diet contained as a protein source WW fortified with essential amino acids (NAS 1978) in amounts such that the essential amino acid composition (milligrams of amino acid/16 g of nitrogen) was equal to that of the RC diet. The FWW diet was fed to one group of rats to see if growth would approach that of animals fed the RC diet.

Protein Digestibility Measurements

Feces were collected on days 18–28 and frozen at −20° C until analyzed for nitrogen by the Kjeldahl method (AOAC 1984; 14.026). Apparent protein digestibility (APD) was calculated for the 10-day period as:

$$\text{APD} = \frac{\text{g nitrogen ingested} - \text{g nitrogen in feces}}{\text{g nitrogen ingested}} \times 100.$$

In vitro protein digestibility of the protein sources was measured using porcine pancreatic trypsin (type IX), porcine intestinal mucosa peptidase, bovine pancreatic α-chymotrypsin (type II), and bacterial protease (type XIV) (Sigma Chemical Co., St. Louis, MO) following the AOAC procedure 43.265.

Pair Feeding Experiment

A group of five male, weanling Sprague Dawley rats arrived in the laboratory one week later than the rats placed on the test diets. These five rats were weight-matched to the initial weights of four rats on the WW diet. The five rats were pair fed the RC diet at the average food intake level of the previous week for each weight-matched WW diet fed rat. The group was maintained on the pair-fed schedule for three weeks.

Statistical Analyses

Data were analyzed by the Student's t test, analysis of variance, and Duncan's new multiple range test (Steel and Torrie 1960).

RESULTS

The amino acid composition of reference casein, the whole grains, and the DDGS are shown in Table III. In general, the relative amino acid concentrations of the whole grain subjected to fermentation were retained in the DDGS. Compared to reference casein, white wheat DDGS contained lower concentrations of seven essential amino acids but equivalent levels of phenylalanine. Lysinoalanine levels were less than the detection limit for the assay (0.04% w/w) in ground white wheat and red wheat and in the DDGS made from these grains.

Chemical scores were calculated using the National Academy of Sciences/National Research Council scoring pattern (NAS 1980). Lysine was the most limiting amino acid in the whole wheat and in the DDGS made from wheat and corn (Table IV).

Noncumulative weight gain and food intake of rats fed the 10% protein diets are described in Table V. During each weekly period, RC rats gained significantly more weight than the FWW rats, and the FWW rats gained more weight than any of the other three test groups. RW rats consistently gained more weight than the CO rats. Food intake was not significantly different between RC and FWW during weeks 1 and 2. However, during the last two weeks, the RC rats consumed more diet than the FWW rats did. Both the RC and FWW rats had higher weekly food intakes than the other three groups. There was no consistent pattern in food intake among the WW, RW, and CO groups.

Total weight gain and food intake measured in the PER assay are shown in Table VI. Weight gain was highest for the RC group, followed by FWW and RW. The WW and CO groups gained the least amount of weight. There were no significant differences in

TABLE IV
Chemical Scores and Calculated Limiting Amino Acids[a]

	Casein	White Wheat Flour	White Wheat DDGS[b]	Red Wheat Flour	Red Wheat DDGS[b]	Corn	Corn DDGS[b]
Histidine	170	150	156	144	142	174	170
Isoleucine	116	85**[c]	92	86	88	85	92
Leucine	129	99	109	99	101	191	193
Lysine	154	58*	55*	55*	48*	55**	44*
Threonine	117	85**	85**	83	86	105	112
Tryptophan	100	92	97	82**	81**	45*	58**
Valine	133	93	105	89	103	100	105
Total sulfur-containing amino acids	102	130	155	136	160	152	155
Total aromatic amino acids	144	108	119	111	111	126	134

[a] Calculated using the scoring pattern in NAS (1980) (Table III). Chemical score = (g amino acid/16 g N of test protein)/g amino acid/16 g N of reference pattern) × 100.
[b] DDGS = Distillers' dried grains with solubles prepared as previously described (Rasco et al 1987a).
[c] * = Most limiting amino acid (by calculation); ** = second most limiting amino acid (by calculation).

TABLE V
Noncumulative Weight Gain and Food Intake of Rats Fed 10% Protein Diets Containing Distillers' Dried Grains with Solubles (DDGS) as the Protein Source

Diet[a]	Weight Gain[b] (g) Week 1	Week 2	Week 3	Week 4	Food Intake[b] (g) Week 1	Week 2	Week 3	Week 4
ANRC reference casein	34.2 ± 3.6 a	33.0 ± 6.8 a	34.7 ± 6.1 a	41.6 ± 5.1 a	90.3 ± 8.0 a	134.5 ± 15.7 a	112.1 ± 11.1 a	147.9 ± 13.0 a
Essential amino acid fortified white wheat DDGS	29.1 ± 3.5 b	28.7 ± 6.3 b	25.3 ± 6.8 b	32.6 ± 14.5 b	91.3 ± 12.8 a	131.6 ± 24.1 a	101.0 ± 10.4 b	129.6 ± 20.8 b
White wheat DDGS	3.0 ± 1.8 cd	0.8 ± 1.7 c	2.4 ± 1.2 c	3.9 ± 1.7 cd	80.7 ± 12.3 b	74.2 ± 12.5 b	52.3 ± 5.4 c	64.6 ± 8.7 c
Red wheat DDGS	4.5 ± 2.1 c	7.0 ± 2.0 d	7.0 ± 2.5 d	8.6 ± 2.2 c	70.0 ± 9.9 c	95.1 ± 23.6 c	71.1 ± 10.9 d	82.7 ± 13.6 d
Corn DDGS	0.6 ± 2.3 d	−0.5 ± 1.3 c	0.1 ± 1.1 c	2.2 ± 0.7 d	63.4 ± 7.7 c	82.3 ± 12.5 bc	50.6 ± 10.6 c	50.7 ± 12.3 e

[a] Composition of diets presented in Table I and II.
[b] Means in the same column not sharing a common letter are significantly different ($P < 0.05$) by analysis of variance and Duncan's new multiple range test ($\bar{x}$ ± SD for 11 rats per group).

total food intake between the RC and FWW groups. The RW group consumed significantly less diet than either the RC or FWW groups. The WW and CO groups had the lowest food intake.

The results of the PER and NPR assays are shown in Table VII. Both the adjusted PER (APER) and relative NPR (RNPR) assays ranked the protein sources in the same order: RC had the highest protein quality, followed by FWW and RW. There was no significant difference between WW and CO, the lowest ranked protein sources.

Protein digestibility measured in vivo and in vitro is reported in Table VIII. Both tests indicated that RC was the most digestible protein source tested. No differences in digestibility were found between RW and WW; CO was the least digestible test protein. In the in vivo test, FWW was less digestible than RC but more digestible than either WW, RW, or CO. A comparison of the in vitro digestibilities of the whole grains and corresponding DDGS revealed that the proteins in soft white wheat and red wheat were significantly more digestible than in the DDGS. The proteins in corn and corn DDGS were equally digestible.

The results of the pair-feeding experiment are shown in Table IX. For comparative purposes, the weight gain of five weight-matched RC rats is included in the table. Although the WW group and the pair-fed RC group had equivalent initial body weights, the WW group gained significantly less weight from week 1 to week 3. The significantly lower body weights of the pair-fed RC group compared to the RC group fed ad libitum from week 1 to week 3 confirm that the pair-fed RC group was receiving a restricted diet.

DISCUSSION

The amino acid composition data revealed that the three types of DDGS retained the amino acid profile of the unconverted whole grains. Lysinoalanine levels in DDGS were not measurable by the method employed, indicating a concentration of less than 0.04 g of lysinoalanine/100 g of DDGS. This corresponds to levels of less than 0.15 g/16 g N in DDGS, less than 0.34 g/16 g N in the whole grains, or less than 400 ppm in both DDGS and the grains. The lysinoalanine concentrations are within the low levels (maximum 1,000 ppm) found in foods commonly consumed in the American diet (Finot 1983). Therefore, from a nutritional standpoint, lysinoalanine levels in these wheat DDGS products do not appear to be of concern.

White and red wheat DDGS are lower than casein in eight essential amino acids; an exception was the phenylalanine content in white wheat DDGS. The essential amino acid patterns in casein, the whole grain flours and DDGS were in agreement with other reports in the literature (Finley 1981; Wu et al 1981, 1984, 1985; Ranhotra et al 1982; Wu and Stringfellow 1982; Sarwar et al 1983; Bookwalter et al 1984; Seligson and Mackey 1984; Wall et al 1984).

Chemical scores inherently have limitations and therefore are only approximations of the nutritional quality. The chemical score calculation indicated that the most limiting amino acid in the wheat flours was lysine, which is consistent with reports by Seligson and Mackey (1984) and Chung and Pomeranz (1985). Lysine was also calculated to be the most limiting amino acid in the three types of DDGS in our study.

One unique feature of DDGS made from wheat and corn is that the high protein content allows the product to be incorporated into a 10% protein diet for PER and NPR assays. Wheat flour was assayed in a 6% protein diet by other researchers (Satterlee et al 1976, Heckler et al 1984). In our study, the RNPR and APER assays ranked the test proteins in the same order. The results of our study indicate that the significantly lower APER and RNPR in the FWW group compared to the RC group were attributable more to differences in weight gain than in food (protein) intake (Table VI). Except for the nearly equivalent food intake of the RC and FWW groups, the food intake and total weight gain of the five dietary groups correlated with the rankings of protein quality (APER and RNPR). The weight gain of the FWW group approached but was not equivalent to that of the RC group; noncumulative weekly weight gain was consistently lower in the FWW group (Table V). The most likely reason for the lower weight gain in the FWW compared to the RC group is lower protein digestibility (Table VIII). However, since the cumulative four-week weight gain of FWW was 81% that of the RC group, we propose that the retarded growth of the WW group was most likely caused by a deficiency of

TABLE VI
Total Weight Gain and Food Intake of Rats at the End of the 28-Day Protein Efficiency Ratio Assay of Distillers' Dried Grains with Solubles (DDGS)

Diet[a]	Total Weight Gain[b] (g)	Total Food Intake[b] (g)
ANRC reference casein	143.5 ± 12.7 a	484.7 ± 36.0 e
Essential amino acid-fortified white wheat DDGS	115.7 ± 18.6 b	453.4 ± 54.6 e
White wheat DDGS	10.1 ± 3.9 c	271.7 ± 22.1 f
Red wheat DDGS	26.8 ± 4.1 d	318.9 ± 51.9 g
Corn DDGS	2.4 ± 3.4 c	247.0 ± 21.2 f

[a]Composition of diets presented in Tables I and II.
[b]Means in the same column followed by different letters are significantly different ($P < 0.05$); analysis of variance and Duncan's new multiple range test ($\bar{x} \pm$ SD for 11 rats per group).

TABLE VII
Protein Efficiency Ratio (PER) and Net Protein Ratio (NPR) of Distillers' Dried Grains with Solubles (DDGS)

Protein Source[a]	PER	APER[a,b]	NPR[c]	RNPR[b,d]
ANRC reference casein	3.0 ± 0.2	2.5 ± 0.2 a	3.6 ± 0.2	100 ± 7 e
Essential amino acid-fortified white wheat DDGS	1.9 ± 0.2	1.7 ± 0.2 b	2.5 ± 0.3	70 ± 8 e
White wheat DDGS	0.3 ± 0.1	0.2 ± 0.1 d	0.9 ± 0.2	25 ± 5 g
Red wheat DDGS	0.7 ± 0.1	0.6 ± 0.1 c	1.3 ± 0.2	36 ± 5 h
Corn DDGS	0.1 ± 0.1	0.1 ± 0.1 d	0.8 ± 0.2	22 ± 5 g

[a]See Tables I and II for diet composition.
[b]Adjusted PER = (PER test protein)/(PER casein) × 2.5.
[c]Averages within the same column followed by different letters are significantly different ($P < 0.05$); analysis of variance and Duncan's new multiple range test ($\bar{x} \pm$ SD, $n = 11$ rats per group).
[d]In the zero protein group, the $\bar{x}$ total weight loss per rat in the 14-day period was 14.8 g.
[e]Relative NPR = (NPR test protein)/(NPR casein) × 100.

TABLE VIII
In Vivo and In Vitro Digestibility of Distillers' Dried Grains with Solubles (DDGS)

Protein Source[a]	% Protein Digestibility In Vivo APD[b] (n)[c]	In Vitro[d] (n)[c]
ANRC reference casein	93.0 ± 0.8 a (11)	89.6 ± 0.7 e (5)
Essential amino acid-fortified white wheat DDGS	88.0 ± 1.5 b (11)	ND[e]
White wheat DDGS	84.0 ± 3.3 c (11)	79.9 ± 0.8 f (3)
Red wheat DDGS	84.0 ± 2.8 c (11)	81.0 ± 0.6 f (3)
Corn DDGS	81.4 ± 3.9 d (11)	77.9 ± 2.1 g (3)
White wheat flour	ND	88.9 ± 1.0 * (3)
Red wheat flour	ND	86.6 ± 0.6 * (3)
Corn	ND	78.4 ± 0.7[f] (3)

[a]See Tables I and II for diet composition.
[b]APD = Apparent protein digestibility = (g N ingested − g N in feces)/(g N ingested) × 100. Different letters within the same column indicate significant differences ($P < 0.05$) by analysis of variance and Duncan's new multiple range test ($\bar{x} \pm$ SD).
[c]Listed in parentheses is either the number of rats per group (in vivo APD) or the number of samples tested (in vitro).
[d]AOAC method 43.265 (1984). * = In vitro protein digestibility significantly higher than in corresponding DDGS ($P < 0.001$; Student's t test).
[e]Not determined.
[f]In vitro protein digestibility not significantly different from that in corn DDGS ($P > 0.05$; Student's t test).

TABLE IX
Average Body Weights of Rats Fed the Following Diets: White Wheat Distillers' Dried Grains with Solubles (DDGS) Ad Libitum, ANRC Reference Casein Pair-Fed, or ANRC Reference Casein Ad Libitum

Diet[a]	Feeding Schedule[b]	n	Weight[c] (g) $\bar{x} \pm$ SD Week 0	Week 1	Week 2	Week 3
White wheat DDGS	Ad libitum	4	53.9 ± 4.0	56.6* ± 3.5	57.3* ± 3.5	60.4* ± 4.7
ANRC reference casein	Pair-fed	5	53.4 ± 3.9	77.5* ± 5.9	91.8* ± 5.4	120.8* ± 11.5
ANRC reference casein	Ad libitum	5	53.2 ± 2.1	90.0* ± 4.3	122.3* ± 5.0	153.6* ± 9.7

[a]See Tables I and II for diet composition.
[b]Pair-fed rats were given the daily amount of food consumed by rats fed the white wheat DDGS diet.
[c]Means in the same column sharing an asterisk indicate significant difference ($P<0.01$) by analysis of variance and Duncan's new multiple range test.

essential amino acids rather than by the presence of antinutritional factors.

The APER and RNPR of DDGS made from red wheat was significantly higher than that made from white wheat or corn. Because the essential amino acid profiles and the digestibility measurements are similar for red wheat DDGS and white wheat DDGS, the reason for the difference in APER and RNPR is unknown.

The APER obtained in the present study for corn DDGS was lower than the values reported by Satterlee et al (1976), Ranhotra et al (1982), and Wall et al (1984) for similar corn products. The APERs for both types of wheat DDGS were considerably lower than those reported by Satterlee et al (1976) for hard red winter wheat and wheat distillers' protein concentrate but comparable to those for white wheat flour reported by Hackler et al (1984) and for wheat gluten reported by McLaughlan et al (1980).

Compared to the whole grains and DDGS products, the protein in reference casein was more digestible by the in vivo (APD) and in vitro tests, and it also had higher quality measured by the PER and NPR bioassays. Fortified white wheat DDGS ranked second to reference casein in protein digestibility and quality. However, white wheat DDGS and red wheat DDGS had equivalent digestibility scores, although in the PER and NPR assays red wheat DDGS ranked significantly higher. The observation that the two whole wheat grains were more digestible than the DDGS by the in vitro test suggests that the chemical or physical properties or both of DDGS make these materials less susceptible to proteolysis by the four enzymes used in the assay. Our APDs for the two types of wheat DDGS and corn DDGS were similar to those reported by Satterlee et al (1976) for wheat and corn distillers' protein concentrates.

The pair-feeding experiment was performed to determine whether lower food (and hence caloric) intake in the WW group was the primary reason for retarded growth. This experiment provided evidence that, despite equal caloric intake, the group fed the WW diet gained significantly less weight than the pair-fed RC group by the end of the first week (Table IX); this trend continued until the end of the third week. The pair-fed RC group received a calorie restricted diet compared to the RC group fed ad libitum. It can be concluded that the lower protein quality of the WW diet was a major factor leading to the retarded growth of the WW diet group.

The noncumulative weekly food intake records show that by week 1, compared to the RC group, the WW group was consuming significantly less diet (Table V). For weeks 1, 2, 3, and 4, the WW group consumed 89, 55, 47, and 44%, respectively, of the amount of diet consumed by the RC group. The reason for the initially suppressed food intake of the WW group, which is representative of the RW and CO groups as well, can only be surmised. Perhaps the DDGS was not palatable to the rats, or the rats were nutritionally stressed, or both. The fact that the FWW group maintained a noncumulative weekly food intake that was *higher* than the other test groups, and equivalent to the food intake of the RC group during weeks 1 and 2, suggests that the flavor of the diet was not the major contributor to suppressed food intake in the WW, RW, and CO groups.

In summary, results of this study indicate that the amino acid profile was not affected by the process that converts whole wheat or corn into DDGS. Chemical scores revealed that lysine was the most limiting amino acid in DDGS made from soft white wheat, red wheat, and corn. The APER, RNPR, and to a certain extent the in vivo and in vitro protein digestibility measurements ranked the test proteins in the same order. All types of DDGS tested had an APER of less than 1.0. Rats fed a diet containing white wheat DDGS plus supplemental essential amino acids had higher growth rates and food intake levels than rats fed an unsupplemented white wheat DDGS diet. Lack of essential amino acids, rather than the presence of antinutritional components, appeared to be the major contributor to the retarded growth observed in rats fed the unsupplemented white wheat DDGS diet.

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