Corn Distillers' Grains and Other By-Products of Alcohol Production in Blended Foods. I. Compositional and Nutritional Studies[1,2]

J. S. WALL, Y. V. WU, W. F. KWOLEK, G. N. BOOKWALTER, and K. WARNER, Northern Regional Research Center, Agricultural Research Service, U.S. Department of Agriculture, Peoria, IL 61604; and M. R. GUMBMANN, Western Regional Research Center, Agricultural Research Service, U.S. Department of Agriculture, Berkeley, CA 94710

ABSTRACT

Cereal Chem. 61(6): 504–509

Potential use of high-protein by-products of alcohol production by grain fermentation in blended food products for the Food for Peace donation program was investigated. Compositional data were obtained on corn distillers' dried grains (CDG) and CDG with solubles (CDGS) from commercial sources and on corn protein concentrates (CPC) obtained by fermenting degermed and dehulled dry-milled corn. Formulations of blended foods that conform to the primary guidelines for overseas donation programs for corn-soy-milk (CSM) were based on computer-derived calculations. These blends, which varied in amounts of cornmeal, soy flour, nonfat dry milk solids (NDMS), and CDG or CPC, were analyzed for protein, fat, ash, crude fiber, and amino acids. Formulations containing 10% CDG had 2.5–2.7% crude fiber, which exceeded the maximum limit of 2%. Levels of lysine were adequate for formulations containing either 5 or 10% corn distillers' grains, but blends containing 10% corn protein concentrates had inadequate levels. Rat-feeding tests were conducted on 12 blended foods to determine protein quality and digestibility. The addition of 10% distillers' grains to a CSM blend decreased the digestibility of solids approximately 2% and protein approximately 4%. The blends containing 5 and 10% CDG gave acceptable values of protein efficiency ratio (PER). Corn protein concentrate of more than 2.5% reduced the PERs of the blends containing 5% NDMS to unacceptable values. Additional processing of distillers' by-products may be required to meet standards for use in blended foods.

The increased production of ethyl alcohol for fuel use by grain fermentation has resulted in availability of large amounts of materials derived from the residual stillage. These by-products are rich in protein (Wu et al 1981) and are used extensively in livestock feeds (Waller et al 1981). Distillers' grains have been incorporated into breads (Tsen et al 1983) and cookies (Tsen et al 1982), with varying degrees of acceptability. It has been proposed that these products be considered for introduction into blended foods for overseas donation programs. Public Law 97-98, Agricultural and Food Act of 1981, Title XII, Section 1208 (U.S. Congress 1981) directs the USDA to investigate potential food uses for protein-rich by-products of alcohol production from grain and evaluate the incorporation of components of these by-products in foods distributed through the Foods for Peace program initiated under PL 480.

For the industrial production of ethyl alcohol, ground corn dispersed in water is heated to gelatinize the starch and is subjected to enzymes to convert the starch to sugars (Wall et al 1983). The sugar solution is fermented by yeast to produce ethyl alcohol. After distilling the alcohol, approximately 30% of the corn solids remain in the residual stillage, which is 8% dry matter and retains most of the protein, fiber, fat, and minerals of the corn (Wu et al 1981). The stillage is then passed through a screen and/or is centrifuged to separate most of the insoluble solids, to yield CDG. The remaining liquid is concentrated to a product called corn distillers' solubles (CDS). These two materials are usually combined to yield CDGS.

The residue from mashing or from fermentation of dehulled, degermed, dry-milled corn after filtration or centrifugation yields a product high in protein and low in lipid and fiber. This product was described and labeled as CPC by Phillips and Sternberg (1979). Because many existing and planned alcohol production facilities can use dry-milled degermed corn meal and can produce CPC, its use in blended foods was also tested as part of our study. Because of its low fiber content, this product is of considerable interest for use in meeting specifications of blended foods.

Blended foods for overseas nutrition programs consist of mixtures of precooked ground cereals, heated defatted oilseed meals, and dried dairy products, supplemented with soybean oil, minerals, and vitamins to provide a balanced source of quality protein, energy, lipids, and other nutrients when served as a porridge, gruel, or extender for other foods. Specifications for the most widely distributed product, CSM, are established by the Agricultural Stabilization and Conservation Service (1981). The general requirements for blended food supplements in the Food for Peace program are described by Bookwalter (1981). Minimum requirements are: energy, 350 kcal/100 g; protein, 18–22%; fat, 6%; and sufficient contents of the essential amino acids lysine, cystine, methionine, tryptophan, and threonine in protein to give a minimum PER of 2.1 and protein utilization of 60%. Crude fiber should not exceed 2%. The product must have acceptable flavor and adequate storage stability, even in tropical climates. Also, the costs must be reasonable, preferably less than 20¢/lb.

We report the composition and nutritional value of CDG and CPC and the conditions necessary for the incorporation of these products in blended foods to meet established nutritional standards for donation programs. Research on physical characteristics, flavor, and storage stability of blended foods containing CDG or CPC are described elsewhere (Bookwalter et al 1984).

MATERIALS AND METHODS

Materials

Brown-Forman (BF) Corp., Louisville, KY, supplied us with BF CDGS and BF CDG, by-products of a typical whiskey production process. The cooked ground grain had been treated with malt to convert starch to sugar. Archer Daniels Midland Corp., Peoria, IL, provided ADM CDGS. Instead of malt, only commercial fungal and microbial enzymes were used to convert starch to sugar during processing. CPC products obtained from Miles Laboratories, Elkhart, IN, and Chemapec Corp., Woodbury, NY, were made by enzymatically converting starch in degermed-dehulled cornmeal to sugars and filtering the CPC residue before fermentation. Pregelatinized cornmeal, toasted defatted soy flour (hereafter designated only as soy flour), and NFDM meeting specifications for CSM were acquired from commercial sources. Animal Nutrition Research Council (ANRC) casein, used as a reference standard in rat feeding tests, was obtained from Nutritional Biochemicals Division, ICN, Cleveland, OH.

BF CDG was ground in an Alpine pin mill at 2 × 18,000 rpm to pass through a 80-mesh screen to meet established standards for fineness and mouthfeel. Considerable difficulty was encountered in grinding the CDG to the required fineness, because the material had a tendency to stick to the stationary pins. This difficulty may

[1]Presented in part at the 68th annual meeting of the American Association of Cereal Chemists in Kansas City, MO, Oct. 30–Nov. 3, 1983.

[2]The mention of firm names or trade products does not imply that they are endorsed or recommended by the U.S. Department of Agriculture over other firms or similar products not mentioned.

have been a reflection of the high oil and fiber content of the CDG. The Miles CPC was ground in the mill at 1 × 14,000 rpm.

Analytical Methods

Proximate analyses were conducted according to the procedures of the American Association of Cereal Chemists (1971). Amino acid analyses were conducted on hydrolyzates of the products with a Glenco automatic amino acid analyzer. Samples containing 1 mg nitrogen (N) were hydrolyzed in 2 ml 6*N* HCl per mg sample by heating under reflux for 24 hr. Recoveries of N in amino acids averaged 95%. Tryptophan was determined directly on enzyme digests by the microbiological procedure of Wooley and Sebrell (1945) by Ral Tech Laboratories, Madison, WI.

Preparation of Blended Foods

Because analyses of BF CDG and Miles CPC indicate that they must be supplemented with foods providing more calories and additional quality protein to offset deficiencies in essential amino acids, the composition and properties of many of their blends with soy flour, NFDM, cornmeal, and other nutrients were computed. A computer program similar to that described by Traver et al (1981) was used for these calculations. CDG and CPC levels were tested at 0, 2.5, 5, and 10%. Levels of soy flour were 6–22%, and NFDM was introduced in the calculations at 5 and 15% levels. Cornmeal was added to these ingredients to give a total of 91.7% of the blend. The remainder of the blend consisted of 5.5% soy bean oil, 2.7% mineral premix, and 0.1% vitamin premixes, as specified in Announcement SSM-1 (Agricultural Stabilization and Conservation Service 1981). Chemical scores were calculated from the amino acid composition to indicate the percentage of the Foreign Agricultural Organization (FAO)(1973) requirement of the limiting amino acid present in the diet protein. Protein level was set at approximately 18%, and selection of ideal blends was based on maximum chemical score (a score of 90 was considered desirable). These calculations provided the basis for compositions used in our study. Blended foods based on computer-derived formulations were mixed in 3,000-g quantities.

Biological Tests

Rat-feeding tests were conducted to determine the nutrient value and digestibility of the proteins in the blended foods. PERs were determined according to standard procedures (AOAC 1975). Diets containing 10% protein derived from the different blends, ingredients, or casein were prepared and used for this testing. However, the cornmeal was tested for PER and digestibility in a diet containing only 6.6% protein and was evaluated by comparison to a casein diet containing only 6.6% protein. Each diet was fed to 10 male Sprague-Dawley (Simonsen Laboratories, Inc., Gilroy, CA) weanling rats for 4 wk. They were individually housed in metal cages with wire bottoms. Food was provided *ad libitum*. The average initial weight of individual animals in the groups was 55–56 g. Weight gain per gram of protein consumed was calculated. These actual PERs were adjusted to values based on a PER of 2.5 for casein. All feces were collected and dried in an air oven, and nitrogen contents were determined on the dried feces. Digestibilities were determined as the amount of the diet solids or nitrogen consumed minus the amount in the feces, divided by the amount consumed, multiplied by 100. Statistical analysis of the feeding data was done by means of the multiple range test of Duncan (1955), except for the cornmeal feeding study, which was subjected to the standard Student *t* test.

RESULTS

Analysis of CDG, CDGS, and CPC

Table I shows compositional data for by-products of alcohol production from industrial sources. The BF CDG contains approximately 25% protein, both CDGS samples contain approximately 28% protein each, and the two CPC samples contain more than 45% protein on an as-is basis. The CDGS and CDG products are high in fat, 9.2–12%, but of the two CPC products, Chemapec CPC has only 3.2% fat and Miles has 11.9%. Fat levels and treatment during processing may contribute to rancidity. Fiber content varied among the products, from 2% for Miles CPC to 15.4% for BF CDG.

Amino acid analyses of protein in CDG, CDGS, and CPC of different origins are shown in Table II. The lysine contents of the protein of CDG and CDGS are both similar to that of whole corn protein; that of the BF CDGS product was a little higher than that of ADM, possibly due to its malt content. Yeast contributes little protein (10%) to CDG. The CPC products had lower lysine contents that did CDG or CDGS, because soluble corn proteins are not recovered in the preparation. All products were considerably lower in lysine than the FAO (1973) requirements shown in Table II. Tryptophan was deficient in these products, and threonine and isoleucine were marginally deficient. Although methionine and cystine levels in CDG, CDGS, and CPC minimally meet requirements for sulfur amino acids, these levels may become insufficient when blends contain added protein from such sources as soy flour, which are far below requirements for sulfur amino acids.

Based on these analyses and on flavor and storage stability investigations, described elsewhere (Bookwalter et al 1984), BF CDG and Miles CPC were selected for further testing as ingredients in blended foods.

Compositions of the Blended Foods

The amounts of cornmeal, soy flour, NFDM, and CDG or CPC used to prepare the various blended food mixtures are shown in Table III. Also given in Table III are the analyses of each blend for the major food constituents, protein, fat, fiber, ash, and moisture. The chemically analyzed compositions were consistent with computer-calculated compositions used to select test formulations. Formulations contained 17–18% protein, 6–7% fat, and 7–8% moisture. Fiber content varied more drastically, depending on the amount of CDG in the blended food. At the 10% CDG level, crude fiber contents of the blends were determined to be 2.5% (2.7% dry basis) with 5% NFDM, and 2.3% (2.5% dry basis) with 15% NFDM. These values are in excess of that established as a maximum for CSM (2% dry basis) in the overseas donor program. They slightly exceeded the values anticipated from calculations obtained from analyses of ingredients. The lower value for fiber in the 10% CDG-15% NFDM blend was due to the replacement of fiber-containing soy flour by milk solids. All CPC-containing blends had very low crude fiber content. Acceptable ash contents of the blends were 3.7–5.1%.

Amino Acid Content of the Ingredients and Blends

Cornmeal, Miles CPC, BF CDG, and ADM CDGS have very low levels of lysine, but soy flour and NFDM proteins had high levels (6 and 8.1%, respectively). Thus, supplementation of cereals with soy or milk products can be expected to elevate lysine contents. Threonine content was marginal in both cereal and soy products. Milk products had slightly higher threonine contents and can contribute to the threonine level in blends. Soy proteins had

TABLE I
Composition (As-Is Basis) of Distillers' By-Products and Other Ingredients for Blended Foods

Distillers' By-Product or Ingredient	*N* × 6.25 Protein (%)	Fat (%)	Crude Fiber (%)	Ash (%)	Moisture (%)
BF CDG[a]	25.3	12.03	15.4	1.63	4.62
BF CDGS[b]	28.5	9.23	8.4	4.32	5.4
ADM CDGS[c]	28	12	7.2	7.12	13.25
Miles CPC[d]	47.7	11.92	2	2.39	7.71
Chemapec CPC[d]	48.3	3.21	7.4	2.80	4.65
Processed cornmeal	7.3	0.53	0.4	0.34	9.83
Defatted soy flour	51.4	1.24	3.1	5.81	6.14
Nonfat dry milk	35.8	0.18	···	8.56	3.83

[a]BF CDG = Brown-Forman corn distillers' dried grains.
[b]BF CDGS = Brown-Forman corn distillers' dried grains with solubles.
[c]ADM CDGS = Archer Daniels Midland corn distillers' dried grains with solubles.
[d]CPC = corn protein concentrate.

low levels of sulfur amino acids, whereas corn proteins had acceptable levels.

These predictions were borne out by the analyses of the blended foods for essential amino acids (Table IV). Increasing NFDM from 5 to 15% significantly increased the lysine content of the blends. Displacing some of the soy flour protein, by increasing NFDM to the 15% level, elevated sulfur amino acids also. Increasing the CDG content of the blend should reduce the lysine level; however, all of the CDG-containing blends had adequate lysine because of fortification with soy flour and NFDM. In contrast, blends containing 10% CPC and only 5% NFDM had inadequate lysine. The highest levels of sulfur amino acids are in those blends with 5–10% CPC and 15% NFDM. Tryptophan was not determined on the blends. All of the other essential amino acids appeared to be adequate in these blends.

Biological Evaluation

Digestibilities for rats consuming 10% protein diets, in which all protein is derived from ingredients of the blends, are shown in Table V. As indicated by the statistical analysis, the variance of measured digestibilities and PERs in each group of rats on a single diet was small and differences between the groups were significant. Diet digestibility was 93% or higher for most blend ingredients, but the diet with BF CDG had a digestibility of only 75.6 ± 1.5%. This poor digestibility was probably due to the high fiber content. For comparison, the digestibility of a diet containing ADM CDGS (not a blend component) was determined to be 88.5 ± 0.05% (Table V), which was consistent with the lower fiber content of the solubles-containing product. Nitrogen digestibilities of these diets (Table V) showed greater variation. Miles CPC nitrogen digestibility, 87.4 ± 0.7%, was comparable to that of defatted soy flour or NFDM diets, but the nitrogenous material in the BF CDG diet was only 64.8 ± 1.45% digestible. The nitrogen in ADM CDGS was 75.9 ± 0.25% digestible. The data indicate that digestibility of protein may have been influenced by fiber content of the product. Digestibilities of solids (97.7 ± 0.03%) and nitrogenous material (88.3 ± 0.16%) in cornmeal was relatively high (Table VI).

Table VII summarizes the total diet and nitrogen digestibilities for 10% protein diets, prepared by mixing blended foods with 5% NFDM or control casein as the source of protein with standard ingredients. Diet 10, which contained a standard CSM blend, showed reduced diet digestibility, compared to the gelatinized starch and casein standard diet, probably due to the fiber content of soy flour and cornmeal. Additions of 5 and 10% CDG to the blends resulted in only small decreases in digestibility of the total diet. However, nitrogen digestibility for the CSM product (diet 10) was significantly less than the control casein diet, due to the poorer digestibility of the cornmeal and soy flour proteins. Additions of 5 or 10% CDG caused small but significant decreases in the protein digestibilities of diets 11 and 12 relative to CSM. Additions of 2.5, 5, or 10% CPC had no significant effect on the protein digestibility of CSM. Because the protein contribution of 5% CPC was similar to 10% CDG, we concluded that the higher level of fiber in the CDG indirectly reduced its protein digestibility.

The digestibilities of blends containing 15% NFDM (Table VIII) and those with only 5% NFDM (Table VII) were very similar. The digestibilities of the NFDM and its protein evidently did not differ appreciably from that of corn, CDG, or CPC proteins.

The results of these digestibility studies showed that addition of 5% distillers' grains did not significantly decrease the digestibility of CSM blends; addition of 10% CDG caused a small but significant decrease in both total and nitrogen digestibilites. However, because of established standards for fiber content (must be below 2%), the 10% CDG would not now be acceptable in blended foods for PL 480 programs. CPC at levels of up to 10% caused no change in digestibility of CSM blends.

PERs reflected both nitrogen digestibilities and amino acid compositions of the tested materials. PERs for ingredients in the blends are shown in Tables V and VI. NFDM gave an adjusted PER of 2.6, whereas the PER for defatted soy flour was 1.98 due to its deficiency of sulfur amino acids. CDG and CPC had low PERs, 0.98 and 0.1, respectively, due to their low lysine contents. The low digestibility of CDG nitrogen also contributed to its poor PER. Cornmeal protein had a PER of only 0.37.

Table VII summarizes the PERs determined by feeding corn-soy-CDG or corn-soy-CPC diet blends containing 5% NFDM. Blends containing 5% and 10% CDG had PERs of 2.3 and 2.22, respectively, compared to a PER of 2.28 for the control CSM blend. The poor digestibility of the protein in the CDG did not markedly diminish the PER of the blends containing only 5 or 10% CDG. Both CDG-containing blends had PERs within the minimum requirements set for blended foods for donation programs. In contrast, when 5% NFDM was included in the blend containing 5 or 10% CPC, the PERs did not meet minimum requirements. To maintain adequate protein quality, a maximum of only 2.5% CPC (Table VII) could be tolerated in blended foods with 5% NFDM.

When the amount of NFDM was elevated to 15% in the blends, all of the PERs increased because of the improved sulfur amino acid and lysine contents of the blends (Table VIII). However, with 10% CPC in the blend (diet 22), the 1.96 PER was not satisfactory. This level of CPC cannot be used even with 15% NFDM in the blends. Evidently, the absence of fiber and better digestibility of the nitrogen in this protein supplement was not sufficient to compensate for its very low lysine content.

DISCUSSION

Cost is an important factor in the selection of ingredients for blended foods for the Foods for Peace donation program. Despite

TABLE II
Essential Amino Acid Composition of Distillers' By-Products and Ingredients of Blended Foods

	Percentage of Protein								
Amino Acid	BF CDG[a]	BF CDGS[b]	ADM CDGS[c]	Miles CPC[d]	Chemapec CPC[d]	Processed Corn-meal	Defatted Soy Flour	Nonfat Dry Milk	FAO Requirement Essential Amino Acids
Lysine	3.3	3.3	2.6	2.1	2.1	2	6	8.1	5.5
Threonine	3.8	4.2	3.3	3.5	3.8	3.9	3.7	4.4	4
Sulfur amino acids (cystine and methionine)	3.3	3.1	2.5	3	3.8	3.4	1.7	2.9	3.5
Valine	5.6	5.7	4.7	6.1	5	5.2	4.4	6.8	5
Isoleucine	3.3	4	3.3	3.6	3.7	3.6	4.2	5.2	4
Leucine	11.7	11.5	10.9	12.3	14.6	10.5	7.2	9.5	7
Aromatic amino acids (phenylalanine and tyrosine)	9.3	9.7	8.6	9.8	10.8	9.2	8.1	10.1	6
Tryptophan[e]	0.4	0.4	0.5	0.4	0.3	0.4	1.4	1.6	1

[a] BF CDG = Brown-Forman corn distillers' dried grains.
[b] BF CDGS = Brown-Forman corn distillers' dried grains with solubles.
[c] ADM CDGS = Archer Daniels Midland corn distillers' dried grains with solubles.
[d] CPC = corn protein concentrate.
[e] Microbiological determination (Wooley and Sebrell 1945).

TABLE III
Composition (As-Is Basis) of Blended Food Formulations Containing Corn Distillers' Grains (CDG) and Corn Protein Concentrate (CPC)[a]

Blend No.	Corn (%)	Soy (%)	Nonfat Dry Milk (%)	CDG (%)	CPC (%)	$N \times 6.25$ Protein (%)	Fat (%)	Crude Fiber (%)	Ash (%)	Moisture (%)
1	64.7	22	5	···	···	18.3	6.07	1	4.22	8.03
2	61.7	20	5	5	···	18.1	6.55	1.7	4.3	8
3	58.7	18	5	10	···	17.6	6.98	2.5	4.18	7.55
4	60.7	16	15	···	···	18.4	5.95	0.8	4.53	7.53
5	59.7	12	15	5	···	18.1	6.51	1.5	4.52	7.2
6	56.7	10	15	10	···	17.3	7.05	2.3	5.08	6.9
7	64.2	20	5	···	2.5	18.3	6.62	1.1	4.03	7.95
8	63.7	18	5	···	5	18.5	6.99	1.3	3.95	7.97
9	64.7	12	5	···	10	17.1	7.27	1.3	3.74	8.35
10	60.2	14	15	···	2.5	18.2	6.26	0.3	4.63	7.67
11	61.7	10	15	···	5	17.4	6.82	0.4	4.51	7.64
12	60.7	6	15	···	10	18.2	6.85	0.5	4.67	8.01

[a] Each contains 5.5% soy oil, 2.7% mineral, and 0.1% vitamin.

the recent fluctuations in grain, oilseed meal, and by-product feed prices, our calculations indicate that the blended foods containing 5% NFDM and 10% CDG (Table III) can be produced at less than 18¢/lb at current market prices. We also incorporated 15% NFDM in blends, because the USDA currently provides NFDM from govenment surplus stocks for use in overseas donation programs at 5¢/lb, which maintains the blend price at less than 18¢/lb.

The satisfactory adjusted PER of 2.22, obtained with the 10% CDG-5% NFDM blend in the rat diet (Table VII), was due to the supplementation of the blend with soy flour and NFDM, which countered the deficiencies in lysine and tryptophan in the CDG and corn proteins. Amino acid analyses indicated that sulfur amino acids were probably limiting in the blends. The use of 10% CDG in 18% protein blended foods is, however, restricted by existing standards that limit to 2% crude fiber levels in the blended foods. Based on the fiber analysis of the blends containing 5% NFDM (Table III), only 7.5% CDG would be acceptable in the blends.

Miles CPC and blends containing CPC had low fiber content, a factor that was considered in selecting CPC for tests in blends. However, due to the low lysine content of CPC (Table II), the blends containing more than 2.5% CPC with 5% NFDM had low

TABLE IV
Essential Amino Acid Composition of Selected Corn-Soy-Milk Blended Foods Containing Corn Distillers' Grain (CDG) and Corn Protein Concentrate (CPC)

	Blend No.[a]												
	1	2	3	4	5	6	7	8	9	10	11	12	
	Percentage of NFDM												
	5	5	5	15	15	15	5	5	5	15	15	15	
	Percentage of CDG						Percentage of CPC						
Amino Acid[b]	0	5	10	0	5	10	2.5	5	10	2.5	5	10	Recommended FAO Levels
Lysine	4	4.7	4.7	5.8	5.2	5.2	4.8	4.4	3.4	5.3	4.7	4.3	5.5
Threonine	3.4	3.6	3.7	4.2	3.5	3.9	3.7	3.8	3.3	3.7	3.5	3.5	4
Sulfur amino acids (cystine and methionine)	2.2	2.1	2	2.4	2.2	2.3	2	2.4	2.2	2.1	2.8	2.8	3.5
Valine	4.5	4.8	4.6	5.6	4.8	4.8	5	5.1	4.5	5.1	4.8	4.9	5
Isoleucine	3.8	4.1	4	4.5	4.4	4.2	3.9	4	3.8	4.2	4.2	4.1	4
Leucine	8.9	9.3	9.7	10.1	9.7	10.1	9.7	10.5	10.5	9.7	10.1	11	7
Aromatic (phenylalanine and tyrosine)	7.7	8.7	8.5	9.3	8.8	9.3	8.7	9.2	8.5	9.1	9	9.6	6

[a] Compositions given in Table III.
[b] Percentage of protein.

TABLE V
Digestibility and Protein Efficiency Ratio (PER)[a] of Corn Distillers' Grain (CDG) and Corn Protein Concentrate (CPC) and Ingredients in Blended Foods

Diet No.	Dietary Source of Protein[a]	Final Body Weight[b,c]	Total Feed Consumption[b]	Percentage of Digestibility: Diet[b,d]	Percentage of Digestibility: Nitrogen[b,e]	PER[f]: Actual[b]	PER[f]: Adjusted
1	ANRC casein control	B 164 ± 5 b	A 326 ± 11 b	A 95.3 ± 0.1 a	A 92.3 ± 0.1 a	A 3.36 ± 0.03 a	2.5
2	Defatted soy flour	C 142 ± 5 c	A 331 ± 16 ab	A 93.2 ± 0.1 ab	B 85.3 ± 0.65 c	B 2.66 ± 0.03 b	1.98
3	Nonfat dry milk	A 180 ± 10 a	A 359 ± 24 a	A 93.9 ± 0.1 ab	AB 88.7 ± 0.05 b	A 3.49 ± 0.05 a	2.6
4	Miles CPC	E 57 ± 2 e	D 166 ± 11 e	A 93 ± 0.2 b	B 87.4 ± 0.7 bc	D 0.14 ± 0.06 d	0.1
5	BF CDG	D 91 ± 4 d	B 274 ± 14 c	C 75.6 ± 1.5 d	D 64.8 ± 1.45 e	C 1.32 ± 0.05 c	0.98
6	ADM CDGS	D 83 ± 2 d	C 217 ± 9 d	B 88.5 ± 0.05 c	C 75.9 ± 0.25 d	C 1.34 ± 0.05 c	1
	S.E.	5.4	17	0.62	0.72	0.046	

[a] Diets contained 10% protein ($N \times 6.25$).
[b] Mean ± S.E. Duncan's multiple range test: means without a superscript letter in common are significantly different: lower case, $P<0.05$; upper case $P<.01$. Rats per group = 10.
[c] Male, Sprague-Dawley rats, initial age = 21 days, initial weight = 55 g.
[d] Diet digestibility = (feed intake-fecal weight)/feed intake × 100.
[e] Nitrogen digestibility = (N intake-fecal N)/N intake × 100.
[f] PER assay 28 days. PER = weight gain/protein intake.

TABLE VI
Digestibility and Protein Efficiency Ratio (PER) of Processed Cornmeal Used in Blended Food Formulations

Diet No.	Dietary Source of Protein[a]	Final Body Weight[b,c]	Total Feed Consumption[b]	Percentage of Digestibility[d] Diet	Nitrogen[b]	PER[e] Actual[b]	Adjusted
7	ANRC casein control (16895-3)	112 ± 4	280 ± 12	95.5 ± 0.42	91.8 ± 0.29	3.01 ± 0.08	2.5
8	Processed cornmeal	61 ± 1 c	165 ± 4 c	97.7 ± 0.03 a	88.3 ± 0.16 b	0.44 ± 0.04 c	0.37

[a] Diets contained 6.61% protein ($N \times 6.25$).
[b] Mean ± S.E. Student's t: a, $P<0.05$; b, $P<0.01$; c, $P<0.00005$. Rats per group = 10. Degrees of freedom = 18 for body weight, feed consumption and PER, and 2 for digestibility.
[c] Male, Sprague-Dawley rats, initial age = 21 days, initial weight = 56 g.
[d] Digestibility of diet = (feed intake-fecal weight)/ feed intake × 100. Nitrogen = (N intake-fecal N)/ N intake × 100. Pooled data, from 7th through 14th test days. Pooled data from two groups of five rats.
[e] PER = weight gain/ protein intake. Assay 28 days.

TABLE VII
Digestibility and Protein Efficiency Ratio (PER) of Blended Food Fomulations Containing Corn Distillers' Grain (CDG) or Corn Protein Concentrate (CPC) with 5% Nonfat Dry Milk Solids

Diet No.	Dietary Source of Protein[a]	Final Body Weight[b,c]	Total Feed Consumption[b]	Percentage of Digestibility Diet[b]	Nitrogen[b]	PER[d] Actual[b]	Adjusted
Series A							
9	ANRC casein control	172 ± 4 a (A)	349 ± 6 bc (AB)	95.5 ± 0.1 a (A)	94 ± 0.05 a (A)	3.35 ± 0.05 a (A)	2.5
	Blend no. and formulation						
10	1 CDG or CPC 0% (CSM)	165 ± 6 a (A)	357 ± 15 ab (A)	92.8 ± 0.4 b (B)	86.35 ± 0.35 b (B)	3.05 ± 0.07 b (B)	2.28
11	2 CDG 5%	165 ± 6 a (A)	357 ± 15 ab (AB)	91.9 ± 0.1 c (B)	84.75 ± 0.95 b (BC)	3.08 ± 0.03 b (B)	2.3
12	3 CDG 10%	163 ± 4 a (A)	364 ± 12 ab (AB)	90.65 ± 0.15 d (C)	82.5 ± 0.7 c (C)	2.98 ± 0.03 b (B)	2.22
13	7 CPC 2.5%	162 ± 4 a (A)	361 ± 12 ab (AB)	92.6 ± 0.1 b (B)	86.35 ± 0.35 b (B)	2.97 ± 0.03 b (B)	2.22
14	8 CPC 5%	162 ± 4 a (A)	384 ± 11 ab (A)	92.55 ± 0.05 b (B)	86.35 ± 0.35 b (B)	2.8 ± 0.05 c (C)	2.09
15	9 CPC 10%	133 ± 3 b (B)	321 ± 12 c (B)	92.5 ± 0.1 b (B)	85.4 ± 0.6 b (B)	2.44 ± 0.03 d (D)	1.82
	S.E.	4.6	11.3	0.18	0.55	0.044	

[a] Diets contained 10% protein ($N \times 6.25$).
[b] Mean ± S.E. Duncan's multiple range test: means without a superscript letter in common are significantly different: lower case, $P<0.05$; upper case, $P<0.01$. Rats per group = 10.
[c] Male, Sprague-Dawley rats, initial age = 21 days, initial weight = 55 g.
[d] PER assay 28 days.

TABLE VIII
Digestibility and Protein Efficiency Ratio (PER) of Blended Food Formulations Containing Corn Distillers' Grain (CDG) or Corn Protein Concentrate (CPC) with 15% Nonfat Dry Milk Solids

Diet No.	Dietary Source of Protein[a]	Final Body Weight[b,c]	Total Feed Consumption[b]	Percentage of Digestibility Diet[b]	Nitrogen[b]	PER[d] Actual[b]	Adjusted
Series B							
16	ANRC casein control (16895-3)	156 ± 6 b (BC)	310 ± 15 c (B)	95.15 ± 0.05 a (A)	92.5 ± 0.4 a (A)	3.23 ± 0.1 a (A)	2.50
	Blend no. and formulation						
17	4 (control) CDG or CPC 0%	179 ± 5 a (A)	387 ± 11 a (A)	95.15 ± 0.25 b (B)	86.4 ± 0.4 b (B)	3.18 ± 0.05 ab (A)	2.46
18	5 CDG 5%	159 ± 6 b (ABC)	345 ± 17 bc (AB)	91.85 ± 0.25 b (B)	85.9 ± 0.5 b (B)	2.99 ± 0.05 b (A)	2.31
19	6 CDG 10%	162 ± 7 b (AB)	353 ± 16 ab (AB)	90.35 ± 0.05 c (C)	84.1 ± 0.3 c (C)	3 ± 0.09 b (A)	2.32
20	10 CPC 2.5%	167 ± 5 ab (AB)	356 ± 13 ab (AB)	92.35 ± 0.15 b (B)	86.05 ± 0.15 b (B)	3.14 ± 0.03 ab (A)	2.43
21	11 CPC 5%	158 ± 3 b (BC)	343 ± 8 bc (AB)	92.35 ± 0.15 b (B)	86.15 ± 0.05 b (B)	2.99 ± 0.04 b (A)	2.31
22	12 CPC 10%	138 ± 3 c (C)	326 ± 10 bc (B)	92.25 ± 0.05 b (B)	86.15 ± 0.05 b (B)	2.53 ± 0.04 c (B)	1.96
	S.E.	5.2	15	0.159	0.313	0.062	

[a] Diets contained 10% protein. ($N \times 6.25$).
[b] Mean ± S.E. Duncan's multiple range test: means without a superscript letter in common are significantly different: lowercase, $P<0.05$; uppercase, $P<0.01$. Rats per group = 10.
[c] Male, Sprague-Dawley rats, initial age = 21 days, initial weight = 56 g.
[d] PER assay 28 days.

PERs. Use of 5% CPC required supplementation with 15% NFDM. The USDA-subsidized use of 15% NFDM depends on continued surpluses, and so, use of CPC in blends cannot be recommended.

A simple dry-milling and sieving of CDG produced a fine fraction with reduced fiber content and elevated protein level (Wu and Stringfellow 1982). The through 35-mesh fraction contained 25% less fiber and could be incorporated at the 10% level into blends, yielding products with less than 2% fiber. However, the elevated protein in the through 35-mesh fraction had less lysine, which requires reformulation of the blend to maintain PER. Such processing would slightly increase the cost of the CDG.

The use of blended foods containing distillers' by-products requires further studies to demonstrate their flavor quality and stability during shipment and storage, especially in tropical areas. Experiments to evaluate the flavor and storage quality of CDG and CPC in blends will be evaluated and procedures for improving flavor in CDG are described elsewhere (Bookwalter et al 1984).

LITERATURE CITED

AGRICULTURAL STABILIZATION AND CONSERVATION SERVICE. 1981. Announcement CSSM-1. Purchase of Corn-Soya-Milk/Instant Corn-Soya-Milk for Use in Export Programs. Kansas City Commodity Office, Kansas City, MO.

APPROVED METHODS OF THE AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1971. The Association, St. Paul, MN.

OFFICIAL METHODS OF ANALYSIS, AOAC. 1975. 12th ed. Association of Official Agricultural Chemists, Washington, DC.

BOOKWALTER, G. N. 1981. Requirements for foods containing soy protein in the Food for Peace program. J. Am. Oil Chem. Soc. 58:455.

BOOKWALTER, G. N., WARNER, K. A., KWOLEK, W. F., WU, Y. V., and WALL, J. S. 1984. Corn distillers' grains and other by-products of alcohol production in blended foods. II. Sensory, stability, and processing studies. Cereal Chem. 61:509-513.

DUNCAN, D. B. 1955. Multiple range and multiple F test. Biometrics 11:1.

FAO. 1973. Energy and Protein Requirements. WHO Tech. Report Series 522, FAO Nutrition Meetings Rep. Series 52. Report of a Joint FAO/WHO Ad Hoc Expert Committee, Rome, Italy.

PHILLIPS, R. O., and STERNBERG, M. 1979. Corn protein concentrate; functional and nutritional properties. J. Food Sci. 44:1,152.

TRAVER, L. E., BOOKWALTER, G. N., and KWOLEK, W. F. 1981. A computer-based graphical method for evaluating protein quality of food blends relative to cost. Food Technol. 35:72.

TSEN, C. C., EYESTONE, W., and WEBER, J. L. 1982. Evaluation of the quality of cookies supplemented with distillers' dried grain flours. J. Food Sci. 47(2):684.

TSEN, C. C., WEBER, J. L., and EYESTONE, W. 1983. Evaluation of distillers' dried grain flour as a bread ingredient. Cereal Chem. 60(4):295.

U.S. CONGRESS. PUBLIC LAW 97-98. 1981. STAT. 95: 1,280.

WALL, J. S., BOTHAST, R. J., LAGODA, A. A., SEXSON, K. R., and WU, Y. V. 1983. Effect of recycling distillers' solubles on alcohol and feed production from corn. J. Agric. Food Chem. 31:770.

WALLER, J., KLOPFENSTEIN, T., and POOS, M. 1981. Distillers' feeds as protein sources for growing ruminants. J. Anim. Sci. 15:1,154.

WOOLEY, J. G., and SEBRELL, W. H. 1945. Microbiological methods for determination of *l*(-) tryptophane in proteins and other complex substances. J. Biol. Chem. 157:141.

WU, Y. V., SEXSON, K. R., and WALL, J. S. 1981. Protein-rich residue from corn alcohol distillation, fractionation, and characterization. Cereal Chem. 58:343.

WU, Y. V., and STRINGFELLOW, A. C. 1982. Corn distillers' dried grains with solubles and corn distillers' dried grains: dry fractionation and composition. J. Food Sci. 47:1,155.

[Received March 12, 1984. Revision received June 25, 1984. Accepted July 2, 1984]