Incorporating Distillers Grains in Food Products[1]

K. A. Rosentrater[2]
USDA, ARS, North Central Agricultural Research Laboratory
Brookings, SD

P. G. Krishnan
South Dakota State University
Brookings, SD

Growing energy requirements coupled with an escalating reliance on nonrenewable fossil fuels from historically volatile regions have led to an increasing need for a secure source of energy for the United States. Biofuels, which are renewable sources of energy, can help meet these energy needs and can be produced from a variety of biomass materials, including residue straw, corn stover, perennial grasses and legumes, and other agricultural and biological materials. At the moment, the most heavily utilized substrate is corn grain. Although directly tied to the market value of the grain itself, industrial ethanol production from corn is accomplished at a relatively low cost compared with other biomass sources.

The number of corn ethanol plants and their processing capacities has increased markedly in recent years. In 2005, 87 manufacturing plants in the United States had an aggregate production capacity of approximately 13.5 billion liters per year. Another 16 plants are currently under construction, and upon completion will produce an additional 2.5 billion liters or more per year (4,17).

In-depth details on ethanol manufacturing, which is beyond the scope of this article, can be found in the literature (12,14,32,40). Briefly, ethanol production from corn grain can be accomplished by wet-mill processing, which is very capital intensive, or dry-mill processing, which has substantially fewer capital and operational requirements and, thus, is rapidly gaining momentum in the industry. The dry-grind production process (Fig. 1) consists of several key steps, including grinding, cooking, liquefying, fermenting, and distilling. Typically three main products are produced in a dry-grind facility: bioethanol, the primary end product; residual nonfermentable corn kernel components, which are increasingly being marketed as distillers dried grains with solubles (DDGS) (Fig. 2); and carbon dioxide.

Distillers grains are removed from the process stream during the distillation stage. They are dried to ensure a substantial shelf life and then sold to livestock producers for use in livestock feed. The sale of distillers grains contributes substantially to the economic viability of ethanol manufacturing, and, as such, is a vital component of each plant's operations. Because of the dynamics of the free market economy under which this industry operates, the quantity of processing residues that will be produced as this industry continues to grow will significantly impact the future of the industry.

Currently, the livestock feed ingredient market is the ethanol industry's only outlet for nonfermentable residues from the manufacturing process, primarily in the form of DDGS and, to a lesser degree, in the form of distillers dried grains (DDG), which do not have added solubles, distillers wet grains (DWG), and distillers solubles (DS). The livestock feed market is well established, but needs to be augmented if ethanol-processing residues are to retain their high-value return, especially as the quantities of these residues generated increase over time. To retain their value, novel uses for these residues (e.g., as ingredients in human food production) should also be investigated.

Because the dramatically increasing demand for ethanol seen in the United States during the last several years is expected to continue for the foreseeable future, the objective of this article is to summarize and review the current literature regarding the utilization of ethanol-manufacturing residues in food products so subsequent value-added applications can be investigated

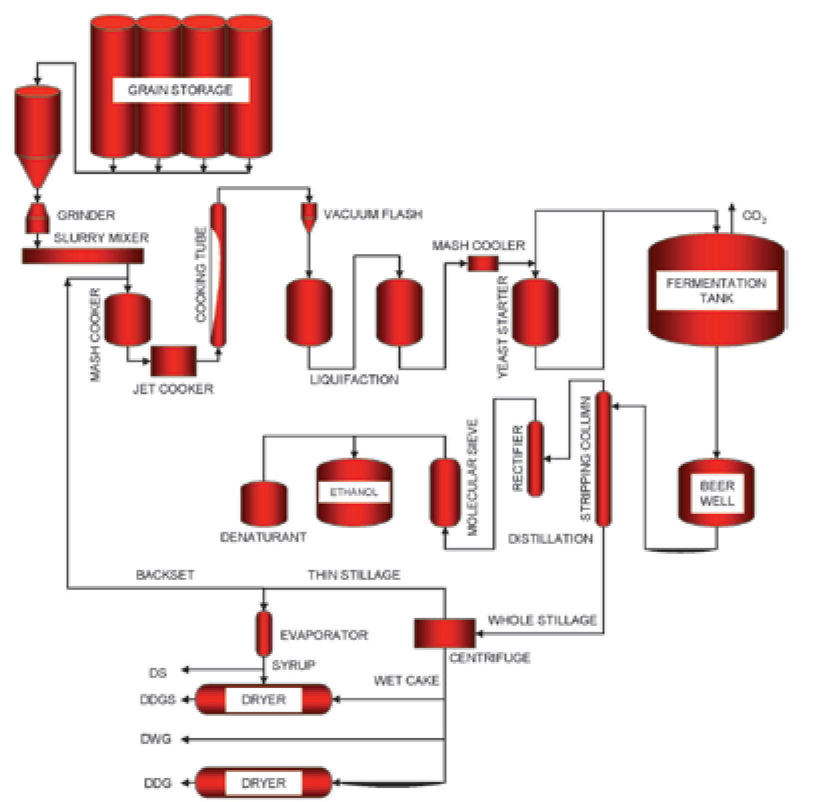


Fig. 1. Process flow diagram of a typical dry-grind corn-to-bioethanol manufacturing plant.

[1] Mention of trade names or commercial products is solely for the purpose of providing specific information and does not imply endorsement or recommendation by the USDA.

[2] Corresponding author. USDA, ARS, North Central Agricultural Research Laboratory, 2923 Medary Ave., Brookings, SD 57006. Phone: 605/693-3241; Fax: 605/693-5240; E-mail: krosentr@ngirl.ars.usda.gov.

DOI: 10.1094/CFW-51-0052

effectively for these materials. This article specifically discusses the inclusion of distillers grains in food products and includes research relating to all cereal grains, not just corn-based ethanol residues. Additionally, ongoing efforts and future prospects for incorporating distillers grains in foods will be discussed.

Prior Investigations

As with many food and organic processing residue streams, feeding ethanol-manufacturing coproducts to animals is a viable utilization method because these materials contain high levels of nutrients. Over the years, numerous research studies have been conducted to optimize the use of processing residues in feed rations. Comprehensive reviews of this research can be found in the literature (3,36). In addition, many studies have been conducted that have examined the use of ethanol-manufacturing residues as functional ingredients in human foods. Table I provides a summary of some of these uses.

The information in Table I provides insight into the number of food products that have been studied and the common themes arising from these investigations. As shown in the table, considerable information has been compiled on food products that could incorporate these residue streams as ingredients. Most of the studies focused primarily on breads and cookies. Other food products, including pastas, blended ingredients, extruded products, and miscellaneous food items, have been investigated to a lesser extent.

There are challenges to incorporating distillers grains in food products. Incorpora-

Table I. Food products developed using ethanol-processing coproducts

Application	Residue[a]	Feedstock	Inclusion Rate (%)	Functionality	Sensory Panel Analysis	Ref.
Blended ingredients	DDD, DDGS	Corn	0, 5, 10	Darker in appearance	Quality poor and unacceptable	5
Blended ingredients	DDG	Corn	5, 7.5	Darker in appearance	Quality poor; solvent extraction improved flavor to acceptable	6
Blended ingredients	DDGS	Corn, red wheat, white wheat	0, 24.73, 29.09, 31.68	Poor growth during rat-feeding trials due to deficient amino acids	…	13
Blended ingredients	DDG, DDGS	Corn	0, 2.5, 5, 10	Acceptable digestibilities during rat-feeding trials	…	38
Bread	DDG	Barley, corn, rye	0, 5, 10, 15, 20	Poor dough development; loaf volume decreased; darker in appearance	Bitter but acceptable	8
Bread	DDG	Sorghum (brown, white, white waxy, yellow)	5, 10, 15	Darker in appearance; loaf volume decreased	Acceptable up to 10%	19
Bread	DDGS	Wheat	12–23	Darker in appearance; reduced loaf volume	…	22
Bread	DDGS	White wheat	20	High concentrations of soluble minerals	…	24
Bread	DDG	Corn and other cereal grains	10, 20	Decreased dough stability; reduced loaf volume and crumb grain; darker in appearance	…	35
Bread: Baguettes	DDGS	White wheat	0, 12.5, 25	Darker in appearance	Less acceptable	25
Bread: Banana	DDGS	White wheat	30	Darker in appearance	Good to excellent	23
Bread: Carrot coconut	DDGS	Barley, corn, rye	0, 40	Darker in appearance; decreased volume	Acceptable to highly acceptable	20
Bread: Cinnamon rolls	DDGS	White wheat	0, 12.5, 25	Darker in appearance	Acceptable	25
Bread: Corn muffins	DDG	Barley, corn, rye	0, 10, 20, 30	Greater water and oil absorption; darker in appearance	Acceptable, but 30% much less acceptable	7
Bread: Dinner rolls	DDGS	Barley, corn, rye	0, 17, 33	Darker in appearance; decreased volume; more chewy	Acceptable to highly acceptable	20
Bread: Doughnuts	DDG	Barley, corn, rye	0, 10, 20, 30	Greater water and oil absorption; darker in appearance	Acceptable, but 30% less acceptable	7
Bread: Dough	DDG, DDGS	Barley, red wheat, soft white winter wheat	0, 4, 8	Darker in appearance; decreased loaf volume; decreased crumb grain coarseness; increased water absorption	…	27
Bread: Hush puppies	DDG	Barley, corn, rye	0, 10, 20, 30	Greater water and oil absorption; darker in appearance	Less acceptable as inclusion increased	7
Bread: Muffins	DDG	Barley	0, 15	Cooked volume increased; water absorption increased	Poor	10
Bread: Nut rolls	DDGS	Barley, corn, rye	0, 33	Darker in appearance; decreased volume	Acceptable to highly acceptable	20
Bread: Oatmeal muffins	DDGS	Barley, corn, rye	0, 5, 15, 36	Darker in color	Acceptable	1
Bread: Oatmeal muffins	DDGS	Barley, corn, rye	0, 33	Darker in appearance; increased volume	Acceptable to highly acceptable	20
Bread: Various	WS	Cereal grains	10–50	…	…	26
Bread: Wheat muffins	DDGS	Cereal grains	0, 10, 15, 20	Lighter in appearance	Off-flavors detected at 20%	29
Bread: White	DDGS	White wheat	30	Darker in appearance	Acceptable to good	23
Bread: Whole wheat	DDGS	White wheat	30	Darker in appearance	Acceptable to good	23
Bread: Yeast rolls	DDGS	Barley, corn, rye	0, 33	Darker in color	Acceptable	1
Brownie	WS	Cereal grains	10–50	…	…	26
Canned: Beef stew	DDGS	Barley, corn, rye	0, 1, 2, 3	…	Acceptable flavor, appearance, and mouthfeel	28
Canned: Chili	DDGS	Barley, corn, rye	0, 1, 2, 3	…	Acceptable flavor, appearance, and mouthfeel	28

(*continued on the next page*)

[a] DDG: distillers dried grains; DDGS: distillers dried grains with solubles; DSG: distillers spent grain; WS: whole stillage.

tion of distillers grains impacts the sensory qualities of food products, especially as inclusion rates increase. In terms of color, most food products become darker in appearance when distillers residues are included. In addition, distillers grains do not contribute the same functionality as the components they replace, including resulting volume and expansion during baking, moisture absorption, texture, and mouthfeel. Incorporation of distillers by-products at relatively high levels in products also results in a definite negative impact on product flavor; such products have typically been rated as marginally acceptable to not acceptable. Flavor can be improved, however, by bleaching and deodorizing distillers grain products prior to inclusion, so the fatty acids and pigments that influence off-flavor development can be neutralized. Due to these challenges, not surprisingly, there is currently no commercial food product that incorporates ethanol-processing residues.

As a direct result of the energy crises of the 1970s, the ethanol industry began a slow but steady growth in the United States and, as evidenced by the studies summarized in Table I, interest in developing food products from distillers grains is not a new concept. During the 1980s, 23 studies were conducted, and 47 food products were investigated. After the 1980s, the ethanol industry continued to grow, but interest in food products from distillers coproducts waned considerably due to the poor sensory qualities of distillers grains ingredients. During the 1990s, only eight studies were conducted, and 10 products were investigated. Thus far in the 2000s, only one

Table I. (***continued from the preceding page***)

Application	Residue[a]	Feedstock	Inclusion Rate (%)	Functionality	Flavor Panel Analysis	Ref.
Canned: Hot dog sauce	DDGS	Barley, corn, rye	0, 1, 2, 3	…	Acceptable flavor, appearance, and mouthfeel	28
Cookie: Bar	DDG	Barley	0, 15, 25	Darker in appearance; decreased width and thickness	Acceptable, but regular still better flavor	34
Cookie: Chocolate chip	DDG	Barley	0, 15, 25	Darker in appearance; decreased width and thickness	No flavor differences	34
Cookie: Chocolate chip	DDG	Sorghum (brown, white, white waxy, yellow)	5, 10, 15	Darker in appearance	Acceptable	19
Cookie: Chocolate chip	DDGS	White wheat	30	Darker in appearance	Good to excellent	23
Cookie: Chocolate chip	DDGS	White wheat	0, 12.5, 25	Darker in appearance	Acceptable	25
Cookie: Molasses	DDG	Sorghum (brown, white, white waxy, yellow)	0, 25, 50	Darker in appearance	Acceptable up to 50%	19
Cookie: Molasses-raisin	DDG	Barley, corn, rye	0, 10, 20, 30	Greater water and oil absorption; darker in appearance	Acceptable	7
Cookie: Oatmeal	DDG	Barley	15	Lipid composition degraded during ethanol processing; bleaching worsened lipid damage	Acceptable; defatted DDG better than defatted bleached DDG, bleached DDG, or DDG	11
Cookie: Spice	DDG	Barley	0, 15, 25	Darker in appearance; decreased width and thickness	Acceptable, but without still had better flavor	34
Cookie: Sugar	DDG, DDGS	Barley, red wheat, soft white winter wheat	0, 2, 4, 8	Darker in appearance; variable spread	…	27
Cookie: Sugar	DDG	Barley	0, 15, 25	Darker in appearance; decreased width and thickness	…	34
Cookie: Sugar	DDG	Sorghum (brown, white, white waxy, yellow)	5, 10, 15	Darker in appearance	Acceptable	19
Cookies: Various	WS	Cereal grains	10–50	…	…	26
Extruded product	DDG	Wheat	0, 10, 20, 40	Darker in appearance; unit density and longitudinal expansion increased; radial expansion decreased	…	15
Extruded product	DDG	Barley, corn, oat, rye, sorghum, wheat	0, 20, 50, 100	Unit density and longitudinal expansion increased	…	16
Extruded product	DSG	Corn	0, 10, 20, 30, 40	Decreased expansion	Acceptable up to 20%; poor quality at greater than 20%	39
Flour	WS	Cereal grains	10–50	…	…	26
Flour	DDG	Corn	100	…	Extraction produced acceptable flavor	41
Granola	DDG	Barley	7.5	…	Not as good	9
Granola bar	DDG	Barley	2.4	…	Not as good	9
Health foods	WS	Cereal grains	…	…	…	33
Ingredient	WS	Wheat	100	Bleaching produced much lighter appearance	Bleaching eliminated flavors and odors	2
Ingredient	DDGS	White wheat	100	Antioxidants did not improve lipid stability; drying method affected lipid stability	…	21
Muesli	WS	Cereal grains	…	…	…	33
Pasta	DDG	Wheat	0, 25, 50	Darker in appearance; cooked weight decreased; lower water absorption	Appearance, flavor, texture acceptable at 25%; unacceptable at 50%	18
Pasta	WS	Cereal grains	10–50	…	…	26
Ready-to-drink	WS	Cereal grains	…	…	…	33
Spaghetti	DDG	Corn	0, 5, 10, 15	Increased cooking loss; decreased firmness	Flavor and texture decreased; more than 15% unacceptable	42
Spaghetti	DDG	Red wheat, rye, sorghum, white wheat	0, 5, 10, 15, 20, 30	Cooking quality acceptable, but lower; darker in appearance	Poor sensory qualities; unacceptable	37
Whole desserts	WS	Cereal grains	…	…	…	33
Yogurt	WS	Cereal grains	…	…	…	33

study and five products have been investigated. Advances have been made, however, in the processing of distillers grains during this time period.

Many improvements and process modifications in ethanol manufacturing have been realized over the years, particularly with the advent of the corn dry-grind production process. Many "next generation" plants are now in operation and, in fact, comprise more than 50% of the industry, while many additional dry-grind facilities are under construction. Dry-grind plants produce distillers grains that differ widely in their nutrient contents and physical properties from those produced by their predecessors—the wet mills of the 1980s (30,31). To expand the use of distillers grains beyond livestock feed as the ethanol industry expands, many plants are increasingly interested in construction and operations that meet the requirements for manufacturing food-grade ingredients. New outlets for food-grade distillers grains are needed, however, and dedicated product development initiatives are required to address the use of new ethanol-processing residues, especially DDGS, to help achieve these ends.

Ongoing Efforts

Corn-based distillers grains are a good source of fiber and protein. Constituents found in the native corn kernel are often concentrated three- to ninefold during ethanol manufacturing, primarily due to the removal of fermentable carbohydrates and subsequent drying operations. These features present many opportunities for utilization of distillers grains in food systems. Food-grade distillers grains have been developed and used successfully in the production of a variety of baked products, such as breads and cookies, at South Dakota State University's test kitchen and food laboratory (sponsored by the South Dakota Corn Utilization Council). Products with substitution levels between 7 and 20% (db) have been developed and evaluated using trained and untrained sensory panels.

The strategy for incorporating distillers grains in food products has involved the development of a flavor-, color- (Table II), and odor-neutral ingredient that has the versatility to be used in a variety of food formulations. Corn distillers grains were acquired from an ethanol plant prior to the addition of preservatives (propionate, benzoate, etc.) during the production process. The material had some remaining solubles that were removed during subsequent treatment in the laboratory. As a result, the distillers grains used in food ingredient formulation resembled traditional DDG rather than DDGS. Mass flow studies are currently underway to determine the fate of low molecular weight constituents that may affect baking functionality.

The DDG first was extensively ethanol-washed, then water-washed and freeze-dried (Fig. 3), and finally ground to a fine particle size in a stainless-steel laboratory mill to produce a DDG flour. Sterilization of the DDG flour, an essential step for food use,

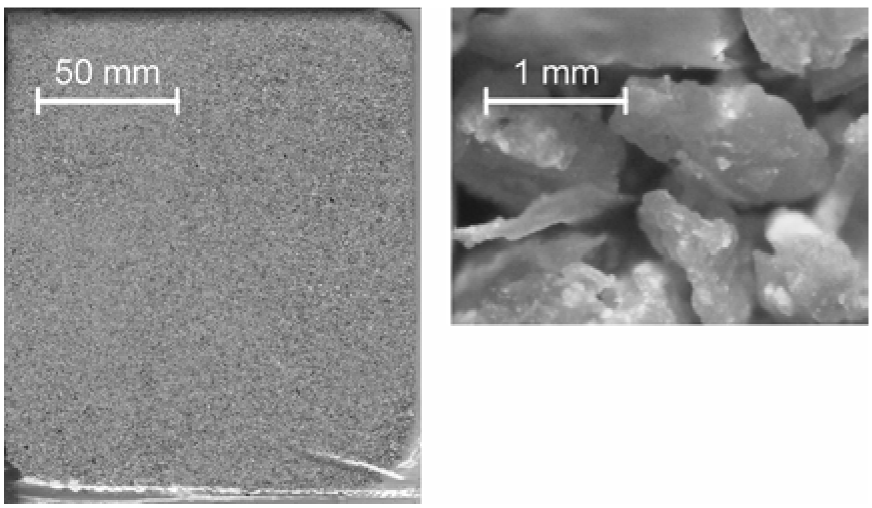


Fig. 2. Nonfermentable residues—distillers dried grains with solubles.

Table II. Various food-grade distillers dried grains, and fractions thereof, used to develop food products

	Control	Water-Washed	Ethanol-Washed	NaOH-Treated (Fiber-Rich Fraction)	NaOH-Treated, Water-Washed (Fiber-Rich Fraction)	NaOH-Treated (Protein-Rich Fraction)
Magnification						
x10						
x60						
x200						
Color						
L	41.69	61.43	70.64	51.78	49.00	69.70
a	7.16	4.71	3.77	8.66	5.07	6.31
b	18.64	24.77	23.45	21.99	18.13	17.78

was accomplished in portion-controlled, sealed cans placed in a food-grade steam sterilizer. Sterilization also accomplished partial deodorization.

The composition and physical properties of the food-grade DDG flour were determined using standard laboratory methods. As shown in Table III, the product had very low heavy metal and mycotoxin contents and, thus, was considered wholesome and safe for human consumption. The properties of DDG depend to a large extent on the quality of the corn used. Ethanol-washing removed lipids, which helped maintain flavor, and pigments, which reduced redness (Table II). Vacuum treatment during freeze-drying and sterilization contributed to deodorization. These steps also extended the shelf life of the DDG.

The DDG flour was blended with wheat flour at various substitution levels in a cross-flow blender for 1 hr. The DDG particle size must be compatible with that of the straight-grade wheat flour for adequate distribution. Ultracentrifugal milling, using a 0.5-mm screen and a sterilizable stainless-steel receiving bowl, produced flour with uniform particle size. Homogeneous distribution of the DDG within the flour blend was critical for subsequent functionality. Production of homogenous DDG-wheat flour blends results in slight changes in water activity. This is undoubtedly a function of moisture migration and distribution within the blend. The freeze-dried DDG flour had an initial moisture content of approximately 5% (w/w), whereas the wheat flour had between 10 and 13% (w/w) moisture content.

Baked products that rely on chemical leavening agents (e.g., cookies) instead of yeast (e.g., breads) had minimal losses in baking functionality and end quality. Cookie batter spread was smaller, however, compared with the control (i.e., all-wheat flour) batter. This was not a negative feature, however, because DDG-flour cookie batter showed consistent behavior, even though cookie diameter was reduced. Functional differences between blends (between 7 and 10% DDG) were not detectable, and cookies produced from blends did not show discernible differences in quality characteristics as judged by a sensory panel (Table IV), except with higher levels of DDG substitution. Color differences in the cookies were discerned using spectrophotometer measurements: *L* (light versus dark) and *a* (red versus green) values were influenced to a greater degree than *b* (yellow versus blue) values (Table V). More information on using distillers grains in cookies can be found in the literature ("Distillers' Grain Cookie Fact Sheet" and "Using Distiller's Dried Grain from Corn in Baked Goods, Extension Extra 14030," South Dakota State University, 1993).

In another study (I. Ahmed, M.S. thesis, 1997), DDG substitution at 0, 5, 7, and 10% (w/w) levels in *chapathi*, an unleavened whole-wheat flatbread, was explored. In this investigation, significant increases in protein and fiber content were noted, particularly at higher substitution levels. Fiber content, as measured by neutral detergent fiber, showed statistically significant gains of 25.7, 43.8, and 51.4% over control *chapathi* (i.e., 0% DDG [w/w]) at 5, 7, and 10% (w/w) substitution levels, respectively. Similar results were noted by Van Everen and coworkers (37) and Wu and coworkers (42) for spaghetti supplemented with DDG. Color and texture were not negatively affected by high DDG substitutions as judged by a trained sensory panel.

Fig. 3. Freeze-drying of food-grade distillers grains.

Future Prospects

Much work remains to be done to effectively incorporate distillers grains into food products, and many potential avenues for research need to be pursued. Further efforts in the development of food-grade distillers grains should include

- Development and scale-up of minimal treatment processes and inputs that can be incorporated easily into existing ethanol plants.
- Determination of the wholesomeness of resulting ingredients.
- Determination of sensory profiles of minimally processed distillers grains.
- Development of an optimal particle size, color, and protein and fiber composition and increased shelf life for use in cereal- and legume-based products.
- Determination of optimal substitution levels and exploration of potential food applications.
- Determination of yeast fermentation metabolites (e.g., nucleic acids and vitamin E isomers) and other functional constituents (i.e., carotenoids, zein, and xanthophylls).

Table III. Properties of food-grade distillers grains developed at South Dakota State University

Proximate Constituent	Level
Protein (%, db)	39.3
Fat (%, db)	9.53
Ash (%, db)	1.55
Carbohydrate (by difference)	
(%, db)	49.62
Neutral detergent fiber	38.0
Total (%, db)	100.0
Moisture (%, wb)	1.70
Heavy metal element (ppm)	
Arsenic	<0.30
Cadmium	<0.05
Copper	5.40
Lead	<0.03
Mercury	<0.10
Selenium	2.06
Mycotoxin (ppm)	
15- Acetyl DON	0.50
15-Acet-scirp	0.50
3-Acetyl DON	0.50
Acetyl T-2	0.50
Aflatoxin	0.02
DAS	0.50
Fumonison B1	5.00
Fusarenone-X	0.50
HT-2 Toxin	0.50
Iso-T-2 Toxin	0.50
Neosolaniol	0.50
Nivalenol	0.50
Scirpentriol	0.50
T-2 Tetraol	1.00
T-2 Toxin	0.50
T-2 Triol	0.50
Vomitoxin	0.20
Zearalenol	0.50
Zearalenone	0.50

Pin-milling and air-classification may provide additional value-added streams that have specific desirable food functionality traits. More information is needed on the "next generation" distillers grains available from newer, more modern ethanol plants that can be readily equipped with automated stainless-steel processing capabilities.

Dry-grind ethanol plants need to have greater quality control over the corn used as starting material, because it is critical to end-product quality. A cleaning or sorting protocol may be needed to ensure the food-grade status of corn entering the plant. Currently, the only pretreatment employed in many plants is a hammer-milling operation to reduce particle size; no "milling" is actually done in the technical sense of the term. Control of granulation, or particle size, is critical for optimal starch conversion and protein recovery. Too fine a grind, however, may lead to diminishing economic returns. Removal of the germ by dry-milling (e.g., dry-grind processing), air-classification, and the introduction of a cleaning step at the beginning of the process may significantly enhance the quality characteristics of potential food-grade distillers grains. The latter steps resemble a wet-milling process in their fractionation objectives.

The production of distillers grains with high-protein, low-fiber fractions and high-fiber, low-protein fractions would be of interest for specific food applications, particularly in view of the current public interest in low-calorie, low-carb, high-protein foods. Wet-extraction techniques that use knowledge of the solubility profiles of DDG proteins can be used to separate protein and fiber constituents. However, such extractions use strong bases and high pH that can result in colors (Table II) and odors that are detrimental to food ingredient characteristics. Milder techniques, such as supercritical fluid extraction (e.g., CO_2), may provide comparable results, although such studies have not yet been completed.

If fractionation is successful, there will be a need to examine potential uses for lower-value streams. For example, gasification of the high-fiber residue from the aqueous separation of DDG fiber and protein is the focus of a current study funded by the DOE and USDA. Other studies should explore the liquefaction potential of lingocellulosic residue from DDG, as well as its various fractions. The resultant bio-oils should then be examined for the potential recovery of useful sugar moieties resulting from acid and low-pressure treatments. The use of supercritical fluid extraction using CO_2 from fermentation (e.g., at an existing ethanol plant) could be an added benefit of this endeavor.

Conclusions

The bioethanol industry is poised to help meet rising U.S. energy demands in the coming years. As output has increased, questions have arisen regarding the nature of the industry, including how to manage the quantity of coproducts that will be generated as the industry grows. Considering how distillers grains ultimately will be utilized is essential to the future of the industry, and as a result, we face a pressing need for research into and development of value-added uses for these coproduct streams. Food products currently are an untapped but potentially high-volume utilization avenue for these materials. Much work remains to be done to develop ingredients from distillers grains that can be used successfully in food products that meet consumer demands for quality and flavor.

Table IV. Sensory panel results for chocolate chip cookies incorporating distillers dried grains (DDG)[a]

DDG Substitution	Excellent	Good	Fair	Poor	Very Poor
30% (w/w)					
Appearance	6	1	0	1	0
Taste	3	3	2	0	0
Texture	3	5	0	0	0
Aroma	0	4	4	0	0
35% (w/w)					
Appearance	5	2	0	1	0
Taste	4	3	1	0	0
Texture	2	5	1	0	0
Aroma	0	5	3	0	0
40% (w/w)					
Appearance	5	2	1	0	0
Taste	1	3	4	0	0
Texture	1	6	0	1	0
Aroma	1	4	3	0	0

[a] Based on a trained panel of eight respondents.

Table V. Properties of chocolate chip cookies incorporating distillers dried grains (DDG)[a]

DDG Substitution	Color			Water
(%, w/w)	*L*	*a*	*b*	Activity
2	59.96	7.40	35.19	0.563
7	56.24	7.44	35.44	0.548
10	57.35	7.46	36.67	0.547
20	46.57	9.02	35.65	0.541
30	48.31	10.12	36.91	0.504

[a] $n = 2$ observations for each property determination.

Acknowledgments

We thank the South Dakota Corn Utilization Council, South Dakota Agricultural Experiment Station, and U.S. Department of Agriculture, Agricultural Research Service for their financial support of this research.

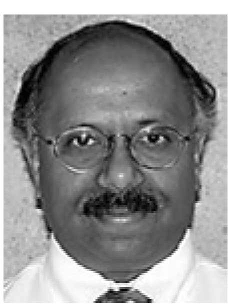
References

1. Abbott, J., O'Palka, J., and McGuire, C. F. Dried distillers' grains with solubles: Particle size effects on volume and acceptability of baked products. J. Food Sci. 56:1323, 1991.
2. Abdel-Aal, E.-S. M., Sosulski, F. W., and Sokhansanj, S. Bleaching of wheat distillers' grains and its fibre and protein fractions with alkaline hydrogen peroxide. Lebensm.-Wiss. Technol. 29:210, 1996.
3. Aines, G., Klopfenstein, T., and Stock, R. *Distillers Grains, MP51.* Published online at http://ianrpubs.unl.edu/fieldcrops/mp51.htm. University of Nebraska Cooperative Extension, Lincoln, 1986.
4. BBI. U.S. fuel ethanol production capacity. Published online at www.bbiethanol.com/plant_production/uspc.html. BBI International, Cotopaxi, CO, 2005.
5. Bookwalter, G. N., Warner, K., Wall, J. S., and Wu, Y. V. Corn distillers' grain and other by-products of alcohol production in blended foods. II. Sensory, stability, and processing studies. Cereal Chem. 61:509, 1984.
6. Bookwalter, G. N., Warner, K., and Wu, Y. V. Processing corn distillers' grains to improve flavor: Storage stability in corn-soy-milk blends. J. Food Sci. 53:523, 1988.
7. Brochetti, D., and Penfield, M. P. Sensory characteristics of bakery products containing distillers' dried grain from corn, barley, and rye. J. Food Qual. 12:413, 1989.
8. Brochetti, D., Penfield, M. P., and Heim-Edelman, M. F. Yeast bread containing distillers' dried grain: Dough development and bread quality. J. Food Qual. 14:331, 1991.
9. Dawson, K. R., Eidet, I., O'Palka, J., and Jackson, L. L. Barley neutral lipid changes during the fuel ethanol production process and product acceptability from the dried distillers grains. J. Food Sci. 52:1348, 1987.
10. Dawson, K. R., Newman, R. K., and O'Palka, J. Effects of bleaching and defatting on barley distillers grain used in muffins. Cereal Res. Commun. 13:387, 1985.
11. Dawson, K. R., O'Palka, J., Hether, N. W., Jackson, L., and Gras, P. W. Taste panel preference correlated with lipid composition of barley dried distillers' grains. J. Food Sci. 49:787, 1984.
12. Dien, B. S., Bothast, R. J., Nichols, N. N., and Cotta, M. A. The U.S. corn ethanol industry: An overview of current technology and future prospects. Page 10 in: *3rd Int. Starch Technol. Conf.—Coproducts Program Proc.* M. Tumbleson, V. Singh, and K. Rausch, eds.

University of Illinois, Urbana-Champaign, 2003.
13. Dong, F. M., Rasco, B. A., and Gazzaz, S. S. A protein quality assessment of wheat and corn distillers' dried grains with solubles. Cereal Chem. 64:327, 1987.
14. Jaques, K. A., Lyons, T. P., and Kelsall, D. R. *The Alcohol Textbook*. K. A. Jaques, T. P. Lyons, and D. R. Kelsall, eds. Nottingham University Press, Nottingham, UK, 2003.
15. Kim, C. H., Maga, J. A., and Martin, J. T. Properties of extruded blends of wheat dried distiller grain flour with other flours. Int. J. Food Sci. Technol. 24:373, 1989.
16. Kim, C. H., Maga, J. A., and Martin, J. T. Properties of extruded dried distiller grains (ddg) and flour blends. J. Food Process. Preserv. 13:219, 1989.
17. Lyons, T. P. Ethanol around the world: Rapid growth in policies, technology, and production. In *The Alcohol Textbook*. K. A. Jaques, T. P. Lyons, and D. R. Kelsall, eds. Nottingham University Press, Nottingham, UK, 2003.
18. Maga, J. A., and Van Everen, K. E. Chemical and sensory properties of whole wheat pasta products supplemented with wheat-derived dried distillers grain (DDG). J. Food Process. Preserv. 13:71, 1989.
19. Morad, M. M., Doherty, C. A., and Rooney, L. W. Utilization of dried distillers grain from sorghum in baked food systems. Cereal Chem. 61:409, 1984.
20. O'Palka, J., Eidet, I., and Abbott, J. Use of sodium bicarbonate and increased liquid levels in baked products containing sour mash corn dried distillers' grains. J. Food Sci. 54: 1507, 1989.
21. Rasco, B. A. Stability of lipids in distillers' dried grain products made from soft white winter wheat. Cereal Chem. 65:161, 1988.
22. Rasco, B. A., and Dong, F. M. Baking and storage stability properties of high fiber breads containing comparable levels of different fiber ingredients. J. Food Process. Preserv. 15: 433, 1991.
23. Rasco, B. A., Downey, S. E., and Dong, F. M. Consumer acceptability of baked goods containing distillers' dried grains with solubles from soft white winter wheat. Cereal Chem. 64:139, 1987.
24. Rasco, B. A., Gazzaz, S. S., and Dong, F. M. Iron, calcium, zinc, and phytic acid content of yeast-raised breads containing distillers' grains and other fiber ingredients. J. Food Compos. Anal. 3:88, 1990.
25. Rasco, B. A., Hashisaka, A. E., Dong, F. M., and Einstein, M. A. Sensory evaluation of baked foods incorporating different levels of distillers' dried grains with solubles from soft white winter wheat. J. Food Sci. 54:337, 1989.
26. Rasco, B. A., and McBurney, W. J. Human food product produced from dried distillers' spent cereal grains and solubles. U.S. patent 4,828,846, 1989.
27. Rasco, B. A., Rubenthaler, G., Borhan, M., and Dong, F. M. Baking properties of bread and cookies incorporating distillers' or brewer's grain from wheat or barley. J. Food Sci. 55:424, 1990.
28. Reddy, N. R., Cooler, F. W., and Pierson, M. D. Sensory evaluation of canned meat-based foods supplemented with dried distillers grain flour. J. Food Qual. 9:233, 1986.
29. Reddy, N. R., Pierson, M. D., and Cooler, F. W. Supplementation of wheat muffins with dried distillers grain flour. J. Food Qual. 9:243, 1986.
30. Rosentrater, K. A., Muthukumarappan, K., Julson, J., and Krishnan, P. Update on ethanol processing residue properties. ASAE Annu. Int. Meet. Pap. 056024. American Society of Agricultural and Biological Engineers, St. Joseph, MI, 2005.
31. Spiehs, M. J., Whitney, M. H., and Shurson, G. C. Nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 80:2639, 2002.
32. Tibelius, C. Coproducts and near coproducts of fuel ethanol fermentation from grain. Published online at http://res2.agr.ca/publications/cfar/index_e.htm. Agriculture and Agri-Food Canada, Ottawa, ON, 1996.
33. Tolle, M. Method for producing foodstuffs, dietetic foodstuffs and food additives on the basis of grain stillage. U.S. patent 6,706,294, 2004.
34. Tsen, C. C., Eyestone, W., and Weber, J. L. Evaluation of the quality of cookies supplemented with distillers' dried grain flours. J. Food Sci. 47:684, 1982.
35. Tsen, C. C., Weber, J. L., and Eyestone, W. Evaluation of distillers' dried grain flour as a bread ingredient. Cereal Chem. 60:295, 1983.
36. University of Minnesota. The value and use of distillers grains by-products in livestock and poultry feeds. Published online at www.ddgs.umn.edu. The University, St. Paul, 2005.
37. Van Everen, K., Maga, J. A., and Lorenz, K. Spaghetti products containing dried distillers grains. Dev. Food Sci. 29:551, 1992.
38. Wall, J. S., Wu, Y. V., Kwolek, W. F., Bookwalter, G. N., and Warner, K. Corn distillers' grains and other by-products of alcohol production in blended foods. I. Compositional and nutritional studies. Cereal Chem. 61:504, 1984.
39. Wampler, D. J., and Gould, W. A. Utilization of distillers' spent grain in extrusion processed doughs. J. Food Sci. 49:1321, 1984.
40. Weigel, J. C., Loy, D., and Kilmer, L. Feed co-products of the dry corn milling process. Published online at www.distillersgrains.com/pdf/drymillingbook.pdf. Iowa Department of Agriculture, Des Moines, 2005.
41. Wu, Y. V., Friedrich, J. P., and Warner, K. Evaluation of corn distillers' dried grains defatted with supercritical carbon dioxide. Cereal Chem. 67:585, 1990.
42. Wu, Y. V., Youngs, V. L., Warner, K., and Bookwalter, G. N. Evaluation of spaghetti supplemented with corn distillers' dried grains. Cereal Chem. 64:434, 1987.

The Authors

Kurt A. Rosentrater, a bioprocess engineer, is a lead scientist with the U.S. Department of Agriculture, Agriculture Research Service, at the Crop and Entomology Research Unit in Brookings, SD, where he is spearheading a new initiative to develop value-added uses for residue streams resulting from biofuel manufacturing operations. His expertise is in value-added product development, alternative recycling and reprocessing strategies for food and organic waste streams, modeling and simulation of food and organic processing systems, economic modeling, and physical and chemical characterization methods. He formerly was an assistant professor at Northern Illinois University, DeKalb, in the Department of Engineering and Industrial Technology, where he taught in the areas of research methods, manufacturing systems, engineering mechanics, and design.



Padmanaban (Padu) G. Krishnan is professor and acting department head, Department of Nutrition, Food Science and Hospitality at South Dakota State University. He holds a Ph.D. degree in cereal science and food technology from North Dakota State University. His expertise lies in the area of analytical methods development and value enhancement of agricultural raw materials. He teaches undergraduate and graduate courses in food chemistry, food analysis, food processing, and research methodology, in addition to maintaining an active research program. His research accomplishments include the development of new analytical methods for folic acid and niacin, food-grade ingredients from corn distillers dried grains, selenium-enriched wheat for health applications, phenolic content of canola, and the evaluation of oat oils for functionality. He also provides technical assistance to food entrepreneurs.