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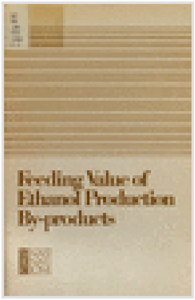


# Feeding Value of Ethanol Production By-products (1981)

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Committee on Animal Nutrition

Board on Agriculture and Renewable Resources

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National Research Council



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CONTENTS

# PREFACE

The Task Force on Feeding Value of Ethanol Production By-products was requested by the Committee on Animal Nutrition to review existing literature on the feeding value and most efficient feed use of ethanol production by-products. High-priority research needs relative to the feeding value, including production, chemical and physical characteristics, storage, and handling of by-products were identified. Emphasis was given to conventional materials and some consideration was given to nonconventional materials used in the production of ethanol.

The task force is indebted to Joseph P. Fontenot of the Committee on Animal Nutrition and to Philip Ross, Executive Secretary, and Selma P. Baron, Staff Officer, of the Board on Agriculture and Renewable Resources for their assistance in production of this report. Special thanks are extended to the members of the Committee on Animal Nutrition, to Tony J. Cunha, Norman A. Copeland, and David Pimentel who reviewed this report for the Board on Agriculture and Renewable Resources and the Commission on Natural Resources for their suggestions and comments, and to Betty Talcott for technical assistance in preparation of the manuscript.

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# SUMMARY

Determining the value of ethanol production by-products involves the integration of a number of factors. However, the importance of establishing the feeding value of these by-products cannot be overstated. By-products contribute significantly to the economic viability of an ethanol production plant. There are numerous alternatives available to produce by-products from ethanol production.

During ethanol production starches and sugars are converted to ethanol. The remaining nutrients are concentrated in the by-products recovered. These by-products contain a 2.5- to 3-fold level of nutrients such as protein, fats, fiber, minerals, and vitamins. Therefore, the production of ethanol converts feedstuffs classified as livestock energy sources to those classified as protein sources. By-products produced from nonconventional feedstocks (e.g., sugar beets, sweet sorghum, vegetable-processing waste) will represent new by-products to be evaluated by nutritionists. These by-products should be evaluated by using methods currently employed in the feed industry when new products are introduced.

The nutrient content of by-products will reflect the nutrient content of the feedstock used in ethanol production. If by-products are used at levels higher than those used in past research, they will need to be more precisely evaluated. Few data exist on many of these by-products that could potentially be used as animal feeds. Since many of these by-products will be used as protein sources, it is suggested that analysis of nutrient content should include parameters normally used in assessing protein sources (e.g., availability of amino acids in the small intestines of monogastrics and postruminally for ruminants).

Dry by-products present no problems with storage and handling. Years of experience with dry by-products has

resulted in clearly defined characteristics for both storage and handling. The quantity of wet by-products is expected to increase greatly because of the potential energy saved by not drying by-products and the inability to dry by-products from farm scale production. Each wet by-product will have unique storage and handling characteristics. Because of limited data, this remains one of the big unknowns in ethanol production. Under today's demands for optimum production from animals consuming by-products, uncertainties concerning storage and handling of by-products could limit the acceptability of the by-products by the livestock industry. The commercial supplement feed industry utilizes dry by-products (less than 12 percent moisture) in formulation of protein supplements and condensed by-products in liquid supplement formulation. Other intermediate moisture products are not normally moved through the existing feedstuff channels. New methods have been adapted for other intermediate moisture by-products such as wet brewers grains, but only after problems on storage and handling had been solved.

The use of dry by-products from beverage ethanol production in animal feeds has been extensively researched. In monogastrics, these by-products have been used to supply supplemental protein, energy, vitamins, minerals, and unidentified growth and intake factors.

Data are limited on the use of high levels of ethanol by-products in the diets of poultry and swine. Studies conducted with high levels of by-products have indicated some limitations with respect to amino acid quality and availability to the animal. In most poultry experiments, by-products have been fed at a maximum of 20 percent of the diet. This level did not result in reduced performance compared to control diets. Ethanol by-products have not usually been tested at higher levels because least-cost diet formulation would restrict the quantity of by-products entering the diet.

The responses noted in experiments using dry by-products in growing and finishing diets for swine are similar to those reported for poultry. The upper limits of feeding have been established on the basis of amino acid quality, particularly lysine and tryptophan content. Most of the data available on feeding value of wet distillery residues were collected from experiments using swine. Performance and carcass desirability would indicate that the wet by-products (less than 10 percent dry matter) should be utilized as a portion of the diet, not as the only feed available.

Dry corn-based ethanol by-products have been used at low levels (7 to 8 percent) in the diet of dogs without nutritional problems. Acceptability problems resulted at high levels (30 percent).

Corn distillers dried grains (DDG), distillers dried grains with solubles (DDGS), condensed distillers solubles (CDS), and corn gluten meal (CGM) have been extensively tested in ruminant diets. Recent developments in ruminant protein metabolism have focused on protein sources that resist degradation in the rumen. All of these by-products, except CDS, have been used in experiments designed to take advantage of this unique characteristic. The target animals for using protein sources that resist degradation in the rumen have been young growing calves on silage-based diets and high-producing dairy cows. These two groups of animals have protein demands that cannot be met by microbial protein synthesized in the rumen alone and therefore must be fed some true protein that resists degradation in the rumen.

The use of DDG, DDGS, or CGM in combination with urea has produced performance equivalent to soybean-meal-supplemented diets for growing cattle. These combinations using ethanol by-products have reduced supplementation cost.

Ethanol by-products, used in high-concentrate finishing diets or in diets for cattle in low-production status, have to compete with sources of nonprotein nitrogen, such as urea, which are generally much cheaper per unit of protein equivalent. Therefore, the optimum classes of ruminants for feeding by-products would be growing calves and lactating dairy cows. The condensed liquid by-products such as CDS have been used in cattle diets as sources of supplemental nitrogen and appear to blend well in the liquid supplement.

By-products produced from food grade feedstocks have not presented health or safety problems to the feed industry. However, as ethanol production moves to nonfood grade or nonconventional feedstocks, close monitoring of by-product quality is needed. Possible contaminants of by-products are heavy metals, pesticides, herbicides, and mycotoxins. These contaminants are normally screened for in feedstuffs entering the feed industry. Nonconventional feedstocks may present new problems with contaminants the industry has not experienced. Nutrient imbalances could occur when ethanol by-products are included as a major portion of the diet or when diets are not properly balanced.

Ethanol by-products will be subjected to regulations by feed control officials to assure product quality of feedstuffs entering animal feed channels. Producers of ethanol by-products will be responsible for compliance with these regulations regardless of feedstock sources or moisture content of by-products. Establishment of the feeding value of ethanol production by-products has been hampered greatly by the lack of an adequate data base. Dry by-products from the beverage alcohol industry have been researched extensively but at low percentages in the diets, and the feedstocks used have been of food grade quality.

With the increased interest in ethanol production from conventional and nonconventional feedstocks in the United States, it is proposed that the following research areas be considered high priorities:

*Reduction of moisture level of ethanol production by-products.* This research should include the development of efficient and more economical methods to reduce moisture content of ethanol by-products. Also, the performance characteristics of various dewatering devices should be evaluated.

Processing methods used for feedstock should be evaluated with by-product moisture reduction as a major criteria.

*Nutritional value of ethanol by-products.* Studies should include characterization of the nutritional value of economically important feedstocks. Changes in the nutritional value should be evaluated across various processing methods. Special emphasis should be placed on protein evaluation of the by-products because these probably will be used mainly as protein supplements. Energy values should be evaluated at increasing levels in the diets for all species.

*Evaluation of physical characteristics of by-products.* Research should focus on the effects of physical characteristics on storage, handling, and feeding of by-products. Data collected from these studies may be used for equipment and storage facility design.

*Increased stability in storage or feed bunker.* Research should be conducted on the use of preservatives for increasing the stability of wet by-products, particularly stillage, both in storage and after by-products are mixed with other feedstuffs.

*Use of ethanol production by-products in animal feeding.* Research should include basic animal metabolism and performance trials with major species of livestock. These by-products should be fed at levels reflecting both protein and energy supplementation of diets. Special consideration should be given to research evaluation factors that optimize the use of nutrients present in the by-product, including economic evaluation.

*Investigating systems for feeding high-moisture by-products.* Methods should be developed to more effectively feed high-moisture by-products to all species of livestock. Blending with other feedstuffs within feeding systems should be evaluated.

*Contaminants and health hazards.* Research should be directed toward deactivation or removal of potential contaminants present in certain feedstocks and by-products.

*Animal product quality.* Research should include studies of the effect of feeding by-products on meat, milk, and egg quality. This should include data on processing, storage, and eating quality.

# INTRODUCTION

Efficient utilization of by-products is vital to the economic viability of ethanol production. Currently, returns from marketing of by-products can offset as much as 50 percent of the initial cost of conventional feedstocks used in ethanol production (Black et al., 1981). As ethanol production increases in the United States, the additional quantity of by-products must be integrated in animal feeding systems if this relationship is to be maintained.

Dry by-products from the beverage alcohol industry have been extensively researched for a number of years. These by-products have been generated from food grade feedstocks under controlled conditions because the ethanol has been produced for human consumption. This has resulted in by-products of predictable quality for use in livestock feeding systems. Also, the feeding value of the by-product has been well established under production levels of the beverage industry.

Ethanol production for fuel could differ greatly from the beverage ethanol industry. First, the feedstocks do not have to be of food grade quality, and nonconventional feedstocks are proposed for ethanol production. Second, the emphasis on energy consumption in ethanol production facilities has resulted in many plants being designed for production of high-moisture by-products. The potential energy savings in shifting from dry to high-moisture products could be approximately one-third the total energy used in the ethanol production plant (Black et al., 1981). Ethanol production on the farm will probably produce high-moisture by-products.

High-moisture by-products should not be considered dry by-products with water added, but entirely new by-products. However, certain characteristics of protein quality (e.g., amino acid composition) do not differ greatly between dry and high-moisture by-products. Heat damage of protein is possible in drying by-products. Research data on the feeding value of high-moisture by-products are limited.

Ethanol production by-products available for future use in livestock feeding will contain larger quantities of dry and high-moisture by-products from conventional feedstocks and a new group of by-products from nonconventional feedstocks. Many factors should be considered in determining the feeding value of ethanol production by-products. These factors do not differ greatly from those normally considered when other by-product feedstuffs have been introduced into livestock feeding systems.

# 1 ETHANOL PRODUCTION AND BY-PRODUCT RECOVERY

## ETHANOL PRODUCTION

A general discussion of ethanol production is presented to show the potential sources for by-product recovery and the resulting physical and chemical characteristics of the by-products. Ethanol production can be separated into five unit operations: feedstock handling and processing, saccharification for starch feedstocks, fermentation, distillation, and by-product recovery and processing. Figure 1.1 shows a flow diagram of the ethanol production process and potential stages where by-products can be recovered. The type of equipment used to process and handle the feedstock affects the types of by-products that can be recovered, and the points where by-products are recovered can affect the design and operation of subsequent unit operations and the nutritive value of the recovered by-product.

### *Feedstock Handling and Processing*

In this report it is assumed that the starch (grains and potatoes) and sugar (sugarcane and sugar beets) feedstocks are harvested and free of debris (e.g., stones, soil, and trash). The starch feedstocks must be ground or milled to facilitate enzymatic hydrolysis of the starch to simple sugars. Conventional grain processing involves grinding or hammer milling to break up the kernels and expose the starch molecules. Recommended particle sizes range from 161 $mm^2$ (Shelton and Rider, 1980) to 32 $mm^2$ (Solar Energy Research Institute, 1980). Smaller particle sizes would result in increased rate and extent of starch hydrolysis but also in higher energy requirements.

Wet milling is another method of processing grain. This

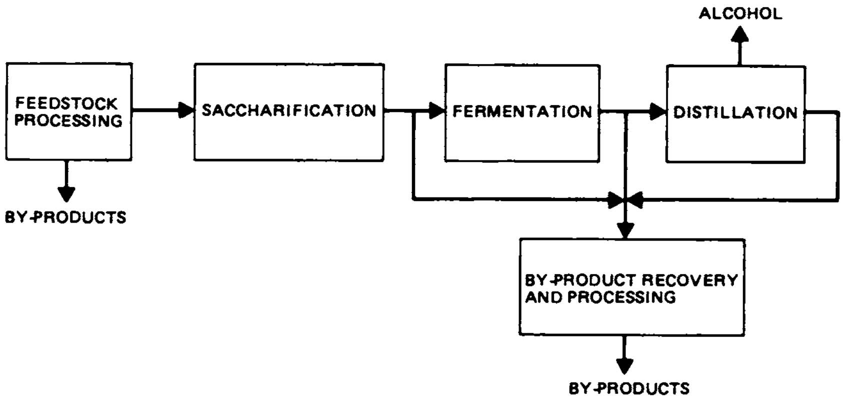


FIGURE 1.1 Flow diagram of the ethanol production process and potential by-products.

process allows recovery of about 99 percent of the feedstock as salable products (Wolnak, 1978). However, the high capital and energy intensiveness of this process makes it applicable for only very large industrial-scale plants.

Figure 1.2 shows the flow diagram of the wet milling process (Wolnak, 1978). The grain is first steeped in an aqueous solution of 5 percent sulfur dioxide to soften the grains and remove soluble materials. The soluble materials extracted in this process are concentrated, and this product is called steep water or steep liquor.

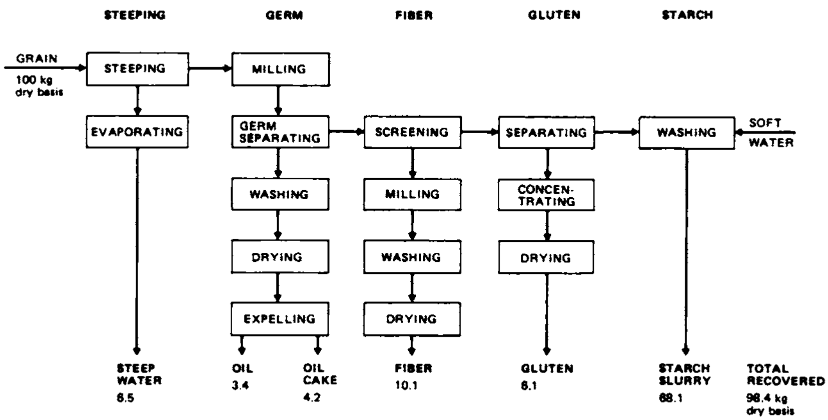


FIGURE 1.2 Grain wet milling process and recoverable by-products (from Wolnak, 1978).

Next, the softened grains are coarse-milled to facilitate the separation of the oil-containing germ. The germ is separated by hydroclones, washed and dried. The dried germ is further processed by solvent extraction to produce oil and oil cake (germ meal).

The germ-free material proceeds through successive screening, milling, and washing steps to remove the hull fiber. The fiber is then dried to produce a product called gluten fiber.

At this point in the wet milling process, a starch-protein slurry is produced. Centrifugation is used to separate the mixture into a high-protein gluten fraction and a concentrated starch fraction. The gluten fraction is further processed and dried to produce a product called gluten meal. The concentrated starch fraction contains nearly 99 percent starch (dry matter basis) and is used as the feedstock for ethanol fermentation. Because of the purity and colloidal nature of the starch fraction, very little particulate matter can be separated during the ethanol production phase. Thus, by-products resulting from ethanol production after wet milling are the condensed or dried fermented solubles and yeast.

Extensive feedstock preparation is necessary to use sugar crops for ethanol production. Sugarcane or sugar beets must be washed and crushed to remove the sugar-containing juice. The juice is then clarified, using commercially available clarifiers and rotary vacuum filters, to remove foreign material. The clarified juices are then concentrated, by using evaporators, to about 20 percent total sugars to reduce distillation costs by starting with a 10 percent ethanol concentration in the material to be distilled. Because of the high feedstock preparation requirements for sugar crops, it is likely that ethanol production from sugar crops will only occur at large plants. Also, because a soluble substrate is used in the ethanol production process, the only feed by-products resulting from this process are the condensed or dried fermented solubles.

### *Saccharification*

When a starch feedstock is used, the starch must be converted to simple sugars, since yeast can ferment only simple sugars to ethanol. The objective is to produce a 14 to 20 percent sugar solution for fermentation to ethanol. The process involves cooking the starch solution to break the cell walls of the starch. The temperature and pH are then adjusted to maximize the enzymatic production of dextrins (polymeric sugars) from starch, and simple sugars (glucose) from dextrin.

*Fermentation*

The fermentation process uses yeast to convert the simple sugars to ethanol and carbon dioxide. The stoichiometric conversion of glucose yields two molecules each of ethanol and carbon dioxide. For the commonly used yeast strains, the optimum fermentation conditions are 27 to 35°C and pH between 3.0 and 5.0. A sugar solution concentration of 16 to 20 percent is a compromise to assure complete conversion of glucose to ethanol (i.e., no end product inhibition) and a high ethanol concentration that reduces the cost for distillation.

*Distillation*

The objective of the distillation process is to separate the ethanol from the ethanol-water mixture. Since ethanol vaporizes at 78°C and water at 100°C, ethanol can be separated from water by heating the ethanol-water mixture at 78°C. The maximum ethanol concentration that can be achieved through conventional distillation is 96 percent. Anhydrous ethanol can be obtained by azeotropic distillation using benzene.

Conventional distillation systems have two types of columns (Figure 1.3): the beer or stripping column and the rectifying or refining column. The purpose of the beer column is to separate the ethanol from the fermented mash mixture (the beer). The beer is introduced at the top and steam is introduced at the bottom of the column. The countercurrent flow of the steam and beer removes nearly all of the ethanol from the beer. Ethanol-water vapor exits from the top of the column at a concentration of about 18 to 20 percent ethanol. The ethanol-water vapor is then introduced into the bottom of the rectifying column and passes countercurrent to the condensed ethanol-water mixture. The vapor leaving the rectifying column is about 95 percent ethanol.

Conventional distillation columns use sieve trays to enhance vapor-liquid contact. Increased vapor-liquid contact can be achieved by using packed columns. However,

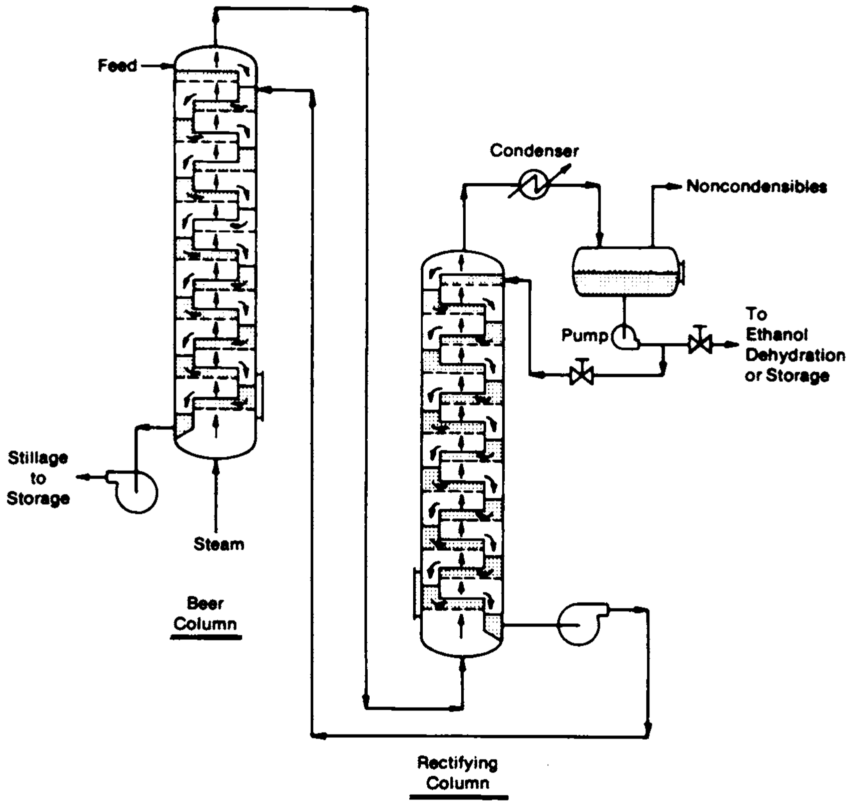


FIGURE 1.3 Schematic diagram of sieve tray distillation of ethanol (from Solar Energy Research Institute, 1980).

because of the potential for clogging, the mash must be separated before distillation in a packed column.

## BY-PRODUCT RECOVERY AND PROCESSING

Figure 1.1 shows the general flow diagram of the ethanol production process and the potential stages where by-products can be recovered. As mentioned previously, the only feed by-products recoverable from sugar crop feedstocks or processes using wet milling of grain are the condensed (50 to 55 percent dry matter) or dried fermented solubles, other than those by-products recovered in the feedstock handling and processing stage.

The beverage-distilling industry recovers feed by-products from the stillage. The stillage has a dry matter content of 5 to 7 percent. The solids are removed by screening and then pressing or centrifuging. The screened solids have a dry matter content of about 15 to 20 percent, and the pressed or centrifuged solids have a dry matter content of about 25 to 35 percent. The pressed or centrifuged solids are dried and sold as distillers dried grains. The thin stillage is condensed in an evaporator and sold as condensed distillers solubles (20 to 40 percent dry matter) or mixed with the dried grain and sold as distillers dried grain with solubles. If the by-products can be consumed within a few days, the screened, pressed, or centrifuged solids can be fed wet.

Several farm-scale ethanol plants remove the grains after the saccharification or fermentation stages. Removal of the grains after the saccharification stage has the potential to reduce the size of the fermentor, lower the power required to pump and mix the mash, and allow the use of packed bed distillation columns. Removal of the grain after fermentation allows the use of packed bed distillation columns. The major disadvantage of removing the grain before distillation is the loss of 30 to 40 percent of the ethanol yield because of the loss of sugar or ethanol in the separated grains. Also, the products may spoil more rapidly with the high concentration of fermentable sugars, and feeding ethanol could cause reduced performance.

## CHARACTERISTICS OF FEEDSTOCK SUBSTRATE

The chemical, physical, and nutritional properties of ethanol production by-products can be influenced by many factors related to the feedstock, the processing procedures, or the types of equipment. DeBecze (1949) listed many factors influencing the composition of distillers grain, especially protein content.

Within a plant, by-product variation is minimized because equipment and processing procedures remain constant. However, the most important influence on the composition of ethanol production by-products is the kind and quality of the feedstock(s) used (Carpenter, 1970). Also, it is commonly known that the nutrient composition of feedstocks varies by year and geographic region. These differences will always exist. Since corn is the predominant grain currently used for ethanol production, most feed products reflect its composition, particularly the protein and fat content. Because a threefold concentration of some nutrients takes place during ethanol production, the composition of the whole stillage can be predicted with a fair degree of accuracy if the nutrient content of the initial feedstock is known (Bauernfeind et al., 1944).

Much less information is available on ethanol production by-products from feedstocks other than grains. Sowa (1973) reviewed the information on molasses stillage for animal feed. This stillage is produced by fermenting either cane sugar molasses or beet sugar molasses. A variety of fruit- and vegetable-processing wastes are available as feedstocks for ethanol production in particular localities. Selection for quality necessarily rejects at least 10 percent of the reported production. About 15 percent of the "field-run" potatoes go into culls when potatoes are packed for the fresh market, and about 20 percent by weight of processed potatoes end up as waste (Nicholson, 1974). Distillation by-products from some of these high-carbohydrate materials (e.g., sugar beets, Jerusalem artichokes) are lower in crude protein content than grains. However, the high concentration of minerals in some of these feedstocks may limit the amount of by-product used in livestock diets.

# 2 CHARACTERISTICS OF ETHANOL PRODUCTION BY-PRODUCTS

## NUTRIENT CONTENT AND UTILIZATION

The nutrient content of ethanol production by-products is related to the nutrient content of the feedstock (Bauernfeind et al., 1944). The fermentation and distillation process removes only the starch or sugar in the feedstock, concentrating the remaining nutrients. For example, when corn (68 percent starch) is used as a feedstock, there is approximately a 300 percent increase in the concentration of the remaining nutrients compared with the level of those nutrients in the original corn feedstock on a per unit weight basis. Table 2.1 contains the nutrient content of possible feedstocks for ethanol production. Also, the quality of by-products is directly linked to the initial feedstock. Contaminants not distilled with the ethanol will concentrate in the by-products.

The nutrient content of ethanol by-products from commonly used feedstocks are presented in Table 2.2 (NRC, 1971). Additional nutrient composition summaries have been published by Carpenter (1970), Reiners et al. (1973), and Reiners and Watson (1975). Nutrient values are not currently available on by-products extracted after saccharification or after fermentation.

Estimates of nutrient variability, expressed as the coefficient of variation for specific nutrients, are not available even on the more common by-products. Since many of these by-products may be used in increasing quantities in the future, data on nutrient variability become imperative. Estimates of by-product variability, within and between ethanol plants, are needed if nutritionists are to design feeding programs to optimize the use of these by-products.

Most of the ethanol by-products are classified as

TABLE 2.1 Average Composition of Possible Feedstocks for Ethanol Production (Percentage)

| | | | | Carbohydrates | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Water | Protein | Fat | Fiber | N-free Extract | Mineral Matter | Ca | P | N | K |
| Sugar beets | 83.6 | 1.6 | 0.1 | 1.0 | 12.6 | 1.1 | 0.04 | 0.04 | 0.26 | 0.25 |
| Molasses beets | 19.5 | 8.4 | 0 | 0 | 62.0 | 10.0 | 0.05 | 0.02 | 1.34 | 4.77 |
| Artichoke tubers | 79.5 | 2.0 | 0.1 | 0.8 | 15.9 | 1.7 | -- | 0.6 | 0.32 | 0.41 |
| Cassava roots, | 67.4 | 1.1 | 0.3 | 1.4 | 28.8 | 1.0 | -- | 0.04 | 0.18 | 0.33 |
| dried | 5.6 | 2.8 | 0.5 | 5.0 | 84.1 | 2.0 | -- | -- | 0.45 | -- |
| Potatoes, tuber | 78.8 | 2.2 | 0.1 | 0.4 | 17.4 | 1.1 | 0.01 | 0.05 | 0.35 | 0.48 |
| Sugarcane | 76.8 | 1.0 | 0.8 | 6.8 | 13.4 | 1.2 | -- | 0.04 | 0.16 | 0.37 |
| molasses, cane, or blackstrap | 26.6 | 3.0 | 0 | 0 | 61.7 | 8.6 | 0.66 | 0.08 | 0.48 | 3.67 |
| Sweet potatoes | 68.2 | 1.6 | 0.4 | 1.9 | 26.7 | 1.2 | 0.03 | 0.04 | 0.26 | 0.38 |
| Corn, dent no. 3 | 16.5 | 8.9 | 3.8 | 2.0 | 67.5 | 1.3 | 0.02 | 0.26 | 1.42 | 0.28 |
| Milo | 11.0 | 10.9 | 3.0 | 2.3 | 70.7 | 2.1 | 0.03 | 0.28 | 1.74 | 0.35 |
| Rice | 12.2 | 9.1 | 2.0 | 1.1 | 74.5 | 1.1 | 0.04 | 0.25 | 1.46 | -- |
| Rye | 10.5 | 12.6 | 1.7 | 2.4 | 70.9 | 1.9 | 0.10 | 0.33 | 2.02 | 0.47 |
| Wheat, hard winter southern plains | 10.6 | 13.5 | 1.8 | 2.8 | 69.2 | 2.1 | 0.05 | 0.42 | 2.16 | -- |
| Raisins, cull | 15.2 | 3.4 | 0.9 | 4.4 | 73.1 | 3.0 | -- | -- | 0.54 | 0 |

Source: Morrison (1961).

TABLE 2.2 Nutrient Composition of Ethanol By-products

| | Corn Distillers Dried Grains (5 02 842) | | Corn Distillers Dried Grains with Solubles (5 02 843) | | Corn Distillers Dried Solubles (5 02 844) | | Corn Gluten Meal (5 02 900) | | Corn Gluten Feed (5 09 903) | | Condensed, Fermented Corn Extractives (5 02 890) | | Sorghum Distillers Grains, Dehydrated (5 08 512) | | Wheat Distillers Grains with Solubles (5 05 194) | | Potato Distillers Dried Residue (5 03 773) | | Sugarcane Molasses Distillers Condensed Solubles (4 03 697) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean Dry | CV ±% | Mean Dry | CV ±% | Mean Dry | CV ±% | Mean Dry | CV ±% | Mean Dry | CV ±% | Mean Dry | CV ±% | Mean Dry | CV ±% | Mean Dry | CV ±% | Mean Dry | CV ±% | Mean Dry | CV ±% |
| Moisture, percent | 6.2 | 3 | 7.5 | 1 | 6.7 | 3 | 9.0 | 1 | 9.6 | 1 | 25.7 | | 6.0 | | 7.5 | 2 | 4.3 | 1 | 4.5 | 2 |
| Ash, percent | 2.4 | 46 | 5.0 | 17 | 8.0 | 22 | 3.6 | 30 | 7.3 | 14 | 8.2 | | 5.0 | | 4.4 | 11 | 7.0 | 18 | 28.7 | 17 |
| Crude fiber, percent | 13.4 | 15 | 9.8 | 23 | 3.8 | 41 | 5.1 | 33 | 8.1 | 6 | 0.0 | | 14.8 | | 10.6 | 22 | 21.5 | 48 | 1.4 | 70 |
| Ether extract, percent | 9.9 | 16 | 11.2 | 30 | 10.0 | 28 | 2.6 | 35 | 2.9 | 7 | 1.6 | | 7.9 | | 6.8 | 26 | 3.2 | 40 | 0.6 | 65 |
| N-free extract, percent | 44.7 | | 44.8 | 10 | 46.7 | | 45.9 | 11 | 53.2 | 1 | 67.4 | | 42.6 | | 43.6 | | 44.3 | | 56.8 | |
| Protein (N × 6.25) | 29.7 | 11 | 29.2 | 2 | 31.5 | 7 | 42.9 | 17 | 28.6 | 7 | 22.8 | | 29.8 | | 34.6 | 12 | 23.9 | 17 | 12.6 | 27 |
| **Energy** | | | | | | | | | | | | | | | | | | | | |
| Chickens, $ME_n$ kcal/kg | 2132 | | 2652 | | 3153 | | 3618 | | 1837 | | | | | | | | | | | |
| Sheep, ME Mcal/kg | 2.95 | | 2.71 | | 3.26 | | 3.06 | | 3.01 | | 3.0 | | 2.97 | | 3.07 | | 2.34 | | 2.44 | |
| Swine, ME kcal/kg | 3915 | | 4050 | | 3373 | | 3373 | | 3523 | | 3889 | | 3624 | | 3613 | | 3135 | | 2898 | |
| Cattle, $NE_m$ Mcal/kg | 1.99 | | 2.16 | | 2.15 | | 1.99 | | 1.93 | | | | | | | | | | | |
| Cattle, NE gain Mcal/kg | 1.33 | | 1.42 | | 1.42 | | 1.33 | | 1.29 | | | | | | | | | | | |
| Cattle, NE lactating cow, Mcal/kg | 2.34 | | 2.49 | | 2.49 | | 2.34 | | 2.27 | | | | | | | | | | | |
| Cattle TDN, percent | 84.3 | | 86.8 | | 86.1 | | 82.8 | | 81.9 | | 85.6 | | 77.6 | | 81.2 | | 63.7 | | 87.0 | |
| Sheep TDN, percent | 81.7 | | 75.0 | | 90.1 | | 84.7 | | 83.3 | | 83.1 | | 82.1 | | 84.8 | | 64.6 | | 67.4 | |
| Swine TDN, percent | 98.7 | | 101.9 | | 85.4 | | 87.6 | | 88.5 | | 96.5 | | 91.3 | | 92.1 | | 78.0 | | 70.3 | |
| **Minerals** | | | | | | | | | | | | | | | | | | | | |
| Calcium, percent | 0.10 | 60 | 0.21 | 21 | 0.37 | 33 | 0.16 | 18 | 0.49 | 46 | 0.95 | | 0.16 | | 0.21 | 28 | | | | |
| Chlorine, percent | 0.08 | 98 | 0.18 | 6 | 0.28 | 23 | 0.08 | | 0.24 | 32 | 0.64 | | | | | | | | | |
| Cobalt, mg/kg | 0.088 | | 0.12 | | 0.211 | 1 | 0.078 | 42 | 0.098 | 68 | | | | | | | | | | |
| Copper, mg/kg | 48.2 | 1 | 66.8 | 30 | 89.4 | 3 | 31.1 | 35 | 52.9 | 35 | | | | | | | | | | |
| Iron, percent | 0.024 | 47 | 0.034 | 42 | 0.059 | 30 | 0.044 | 35 | 0.051 | 7 | | | | | | | | | | |
| Magnesium, percent | 0.07 | 61 | 0.27 | 32 | 0.69 | 17 | 0.05 | 87 | 0.32 | 44 | 2.01 | | | | | | | | | |
| Manganese, mg/kg | 24.0 | 41 | 30.8 | 55 | 79.4 | 21 | 11.6 | 31 | 26.4 | 29 | | | | | | | | | | |
| Phosphorus, percent | 0.43 | 41 | 0.85 | 18 | 1.48 | 26 | 0.51 | 35 | 0.86 | 20 | 2.65 | | 0.82 | | 0.77 | 17 | | | | |
| Potassium, percent | 0.18 | | 0.70 | 45 | 1.88 | 5 | 0.03 | 91 | 0.63 | 20 | 3.81 | | | | | | | | | |
| Sodium, percent | 0.10 | 47 | 0.39 | 93 | 0.26 | 36 | 0.11 | 32 | 1.05 | 4 | | | | | | | | | | |
| Sulphur, percent | 0.46 | 19 | 0.32 | 21 | 0.40 | 2 | | | 0.24 | 98 | 0.64 | | | | | | | | | |

TABLE 2.2 (Continued)

| | Corn Distillers Dried Grains (5 02 842) | | Corn Distillers Dried Grains with Solubles (5 02 843) | | Corn Distillers Dried Solubles (5 02 844) | | Corn Gluten Meal (5 02 900) | | Corn Gluten Feed (5 09 903) | | Condensed, Fermented Corn Extractives (5 02 890) | | Sorghum Distillers Grains, Dehydrated (5 08 512) | | Wheat Distillers Grains with Solubles (5 05 194) | | Potato Distillers Dried Residue (5 03 773) | | Sugarcane Molasses Distillers Condensed Solubles (4 03 697) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean Dry | CV ±% | Mean Dry | CV ±% | Mean Dry | CV ±% | Mean Dry | CV ±% | Mean Dry | CV ±% | Mean Dry | CV ±% | Mean Dry | CV ±% | Mean Dry | CV ±% | Mean Dry | CV ±% | Mean Dry | CV ±% |
| **Vitamins** | | | | | | | | | | | | | | | | | | | | |
| Biotin, mg/kg | 0.48 | 98 | 0.72 | 53 | 1.61 | 51 | 0.22 | | 0.37 | | | | | | | | | | | |
| Carotene, mg/kg | 3.3 | 98 | 4.1 | 79 | 0.7 | 27 | 18.0 | 61 | 9.3 | 49 | | | | | 2.6 | | | | | |
| Choline, mg/kg | 1431 | 9 | 3043 | 2 | 5189 | 3 | 363 | 22 | 1674 | 53 | | | | | | | | | 1884 | 66 |
| Folic acid, mg/kg | | | 89 | 42 | 1.21 | 24 | 0.24 | 5 | 0.34 | 34 | | | | | | | | | 0.18 | |
| Niacin, mg/kg | 36.9 | 49 | 79.8 | 17 | 124.1 | 18 | 55.0 | 19 | 79.4 | 19 | | | | | 81.0 | 28 | | | 68.1 | 49 |
| Pantothenic acid, mg/kg | 6.1 | 47 | 13.9 | 43 | 22.5 | 30 | 11.4 | 35 | 18.9 | 28 | | | | | 13.1 | 15 | | | 50.1 | 15 |
| Riboflavin, mg/kg | 3.2 | 70 | 10.9 | 30 | 18.2 | 38 | 1.7 | 46 | 2.7 | 59 | | | | | 11.4 | 25 | | | 45.2 | 98 |
| Thiamine, mg/kg | 1.9 | 63 | 3.1 | 47 | 7.3 | 47 | 0.2 | 88 | 2.2 | 75 | | | | | | | | | | |
| Vitamin A equiv. | 5.6 | | 6.8 | | 1.2 | | 30.0 | | 15.4 | | | | | | 4.4 | | | | | |
| **Amino Acids** | | | | | | | | | | | | | | | | | | | | |
| Arginine, percent | 1.07 | 6 | 1.11 | 15 | 1.13 | 39 | 1.48 | 19 | 0.88 | 18 | 1.01 | | | | 1.19 | 7 | | | | |
| Cystine, percent | 0.42 | | 0.39 | | 0.49 | | 0.71 | | 0.22 | | | | | | | | | | | |
| Glutamic acid, percent | | | 5.98 | 9 | 4.62 | 11 | 9.15 | 13 | 4.76 | 9 | | | | | 9.30 | 11 | | | | |
| Glycine, percent | | | 0.72 | | 1.18 | 37 | 1.65 | 11 | 1.64 | | | | | | | | | | | |
| Histadine, percent | 0.65 | 9 | 0.76 | 13 | 0.75 | 5 | 1.10 | 4 | 0.66 | 12 | 0.85 | | | | 0.85 | 5 | | | | |
| Isoleucine, percent | 1.08 | 11 | 1.85 | 13 | 1.61 | 7 | 2.54 | 10 | 1.33 | 24 | 0.83 | | | | 2.05 | 13 | | | | |
| Leucine, percent | 3.90 | 6 | 2.39 | 14 | 2.26 | 42 | 8.38 | 22 | 2.88 | 18 | 2.12 | | | | 2.16 | 38 | | | | |
| Lysine, percent | 0.91 | 7 | 0.83 | 12 | 0.97 | 46 | 0.82 | 10 | 0.88 | 9 | 0.95 | | | | 0.86 | 9 | | | | |
| Methionine, percent | 0.48 | | 0.54 | 20 | 0.59 | 33 | 1.10 | 29 | 0.33 | 12 | 0.51 | | | | 0.54 | | | | | |
| Phenylalanine, percent | 0.65 | | 1.85 | 15 | 1.61 | 10 | 3.20 | 42 | 1.00 | 20 | 0.82 | | | | 2.05 | 10 | | | | |
| Serine, percent | | | 1.74 | 5 | 1.40 | 19 | 1.65 | | 0.89 | | | | | | 1.84 | | | | | |
| Threonine, percent | 0.33 | | 1.09 | 3 | 1.07 | 18 | 1.54 | 19 | 0.89 | 9 | 1.00 | | | | 1.08 | 7 | | | | |
| Tryptophan, percent | 0.22 | | 0.20 | 17 | 0.24 | 33 | 0.23 | 43 | 0.22 | 18 | 0.15 | | | | 0.43 | 55 | | | | |
| Tyrosine, percent | 0.98 | 5 | 0.65 | 10 | 0.75 | 32 | 1.10 | | 1.00 | 28 | | | | | 0.65 | 13 | | | | |
| Valine, percent | 1.30 | 11 | 1.84 | 6 | 1.61 | 10 | 2.43 | 26 | 1.44 | 22 | 1.48 | | | | 2.05 | 6 | | | | |
| Xanthophylls, mg/kg | 11.55 | | 10.62 | | 2.37 | | 72.36 | | 36.26 | | | | | | | | | | | |

Numbers in parentheses in heads are International Feed Numbers.

protein supplements; thus, additional nutritive analyses on nitrogen and protein composition are needed. These analyses should include nonprotein nitrogen, digestion coefficients, and availability of amino acids for major species.

## PHYSICAL CHARACTERISTICS

### *Wet By-products*

The most important consideration in evaluating wet distillers products is the dry matter content. Dry matter will likely have to be determined on each batch and possibly at each feeding with wet products such as stillage, because the solids will tend to settle, creating a large differential in dry matter content of different levels in storage.

Because of the large variety of wet by-products available from ethanol production and the limited time these by-products have been available, data are limited on the physical characteristics of wet by-products.

### *Dry By-products*

Most of the typical products that might result from the increased production of ethanol from cereal grains have been well-defined and characterized by groups such as the Association of American Feed Control Officials (AAFCO) and the American Feed Manufacturers Association (AFMA). The AFMA has developed recommended purchasing guidelines for these products that may be useful for producers contemplating the sale or purchase of these products. This purchasing guideline is presented in Appendix B.

# 3 STORAGE AND HANDLING OF ETHANOL BY-PRODUCTS

## WET BY-PRODUCTS

Handling ethanol distillation by-products in the wet form eliminates the cost of installing and operating drying equipment. In addition to the continually increasing energy costs of drying, associated air pollution concerns and pollution control costs must be considered.

The wet form is probably the only economical choice for utilizing by-products from small ethanol plants. However, medium- and even large-sized distillation plants located within range of adequate livestock feeding units should seriously consider partial dewatering as a viable alternative to dehydration for marketing feed by-products.

Conventional distillers feeds are products resulting from the yeast fermentation of cereal grains. An alternate approach attractive for large plants is to initially wet mill the corn, separating out the starch, gluten, and germ and producing various feed products. The starch can then be fermented for ethanol production. Advantages to wet milling the corn are the greater flexibility in starch use, separating out the useful oil, and higher concentrations of protein in certain of the feed products (e.g., corn gluten meal).

The following is a list of wet feed by-products that may be available from ethanol distillation plants:

- distillers wet grains
- stillage
- condensed distillers solubles
- distillers wet grains with solubles
- wet corn bran
- condensed fermented corn extractives

- wet corn gluten feed
- distillers wet yeast

*Distillers Wet Grains*

Dry matter content, as well as storage and handling characteristics, is the main determinant of nutritive value on a wet basis. Dry matter content varies from 15-20 percent with screening to 25-35 percent with centrifugation of whole stillage. The ideal dry matter content would appear to be 25-30 percent. Drier material is too light and fluffy, enabling oxygen penetration and more rapid spoilage. On the other hand, with wetter materials (<25 percent dry matter) seepage or runoff occurs. This runoff should be collected and could possibly be disposed of on land if consistent with environmental standards and crop yields.

Special truck boxes equipped with rubber sealed endgates and turn buckle clamps are necessary to eliminate drip losses in transit. Drippage means pollution of city streets and highways as well as loss of nutrients. In northern regions it is desirable for the truck boxes to be insulated to prevent freezing in the winter. Some truckers using uninsulated boxes sprinkle salt at the front of the box to reduce freezing.

Storage qualities of distillers wet by-products are similar to brewers wet grains, a material that has generally been stored successfully. Fresh distillers wet grains have a pH of 4.0 with a temperature of 71°C. For short-term storage, wet grains should be stored off the ground in a pit silo, on a cement slab or wooden platform or in a wooden box. The material stores satisfactorily for 4 to 5 days in hot weather and 6 to 8 days or longer in cold weather. It is important to minimize exposed surface area to minimize surface spoilage in the summer and also to maximize heat retention in the winter (Linton, 1973). Ideally, the storage unit should be only slightly wider than the dump truck to minimize the exposed surface. Sometimes a small amount of common salt is sprinkled over the surface of distillers wet grains to reduce a fly problem and assist in reducing surface spoilage in the summer. A foldaway roof over the storage pit is a good investment to protect the product from direct sun, rain, or snow. Of course, once the wet grains are removed from storage, bunker life is short; thus twice-daily feeding is desirable. With time, very distinct off-color and off-odor occur.

Distillers wet grains are easily handled by using a front-end loader and mixer feed wagon or truck combination. For automatic feeding systems, an automatic pit unloader is available (McDougall and Linton, 1976). This device removes from the top surface of the grain pile, thus eliminating surface spoilage.

Long-term storage of wet grains may be necessary to reduce fluctuations in supply and demand. A tight plastic seal over wet grains stored in a horizontal silo or on a cement slab minimizes oxygen diffusion into the material and thus reduces aerobic microbial activity. This may double the effective short-term storage life of wet grains containing no preservatives. However, attempts to ensile distillers or brewers wet grains have resulted in poor quality silage with characteristic offensive odors and high dry matter losses (Allen and Stevenson, 1975). The properties of these wet grains, a low dry matter and low soluble carbohydrate material, are similar in many ways to those of common direct-cut forages. For long-term storage (i.e., several months), the addition of 0.5 percent weight/weight formic acid has proven effective with brewers wet grains (Allen and Stevenson, 1975) and direct-cut forages (Barker et al., 1973). Lower levels of formalin were effective in preserving liquid whey (Muller, 1979), while higher levels of propionic acid were needed to preserve high-mositure corn and other grains (Jones et al., 1974). Bunker life would also be increased with treated distillers wet grains. Mixing other feedstuffs (such as corn and molasses) with brewers wet grains improved ensiling characteristics but was not as effective as adding formic acid (Allen and Stevenson, 1975). While effective, the abovementioned organic acids are expensive, and their use for long-term preservation of distillers wet grains is questionable.

### *Stillage*

Dry matter content of stillage varies widely. Whole stillage varies from a low of 5 percent to a high of 13.9 percent dry matter if 50 percent of the stillage can be recycled. In making ethanol for beverage use, no alkali can be added to neutralize any recycled stillage. However, alkali additions are allowed in the case of ethanol for fuel production. High stillage recycling greatly reduces the amount of water needed for the process, thus reducing the heat (energy) required and the moisture content of the stillage.

If screening is used to remove the coarse grain fraction of the whole stillage, the remaining thin stillage contains 4 to 5 percent dry matter (2 percent as dissolved solids and 2 to 3 percent as suspended solids). Following centrifugation the thin stillage contains 2 percent dry matter. The sedimentation rate of stillage is quite rapid. However, the maximum dry matter content obtainable with settling is only 12 percent, assuming 6 to 7 percent dry matter whole stillage (J. A. Linton, Miracle Feed Co., London, Ontario, personal communication).

While dry matter content of either whole or thin stillage varies, all stillage must be handled in liquid storage, transporting, and feeding systems. However, the feeding value or market value of stillage per ton is directly related to its dry matter content.

A storage tank needs to be provided at the distillery sufficient for probably a 2-day production of stillage. The material may be transported by tanker truck (e.g., 150-$m^3$ capacity) and deposited in tanks ideally of at least similar size at the livestock feeding unit (tanks of 150 to 300 $m^3$ are being used). Small livestock operators may transport stillage daily, directly from the plant, using smaller tanks or even drums mounted on trailers or trucks. The farm storage tanks should be horizontal, agitator-equipped, and insulated when used in colder regions. Temperature extremes should be minimized, and a sheltered location from the summer sun and winter winds is desirable. Temperature of stillage when produced approximates 71°C. Rather than insulate, some operators locate their storage tanks below ground. Tanks made of mild steel appear adequate.

Stillage decomposes rapidly, especially during warm weather and on exposure to air. Thus the material should be stored in sealed tanks and fed within 1 to 2 days, at least during warm weather. Longer storage in warm weather probably results in significant nutrient losses although the extent of these losses has not been quantified. Palatability can be maintained for 3 to 5 days. However, sour stillage is unpalatable and can cause serious digestive upsets. The pH of fresh stillage is 4.3. When stillage can be produced, delivered, and fed within 24 hours, little nutrient loss and few palatability problems occur.

Twice-daily feeding of stillage is probably necessary in both summer and winter. In warm weather, frequent feeding reduces bunker spoilage and resultant palatability problems. On the other hand, if the temperature reaches very low levels, the potential exists for freezing of the stillage unless consumed rapidly.

Stillage can be fed separately in open tanks or troughs, either by free choice or limit fed by time. It is also possible to combine stillage with roughage and concentrates in conventional mixer-feeder wagons or trucks. In the latter case, bunkers should be capable of holding feeds containing large amounts of liquid. Concrete bunkers are probably adequate with some sealing of the joints. However, acid feeds do cause erosion of concrete. Slurry feeding systems have some advantages and should be considered especially with feeding swine. Equipment has been developed, particularly in Europe, and should be available for stillage with little modification.

Stillage produces diets of unique physical form, odor, and palatability. When high levels of stillage are fed to high-producing animals, fresh stillage should be constantly available to maintain high feed intakes. Frequent interruption of supply would drastically reduce the usefulness of stillage as a livestock feed. When the distillery must shut down for long periods of time (longer than 2 days), emergency feed supplies might be supplied by substituting somewhat similar type of wet feeds from other distilleries or breweries in the area or by reconstituting dried material. Some preservatives could be used to maintain emergency supplies or increase the storage life of stillage, but little research has been done to determine the types of preservatives and their overall economics.

### *Condensed Distillers Solubles*

Moisture content varies but commonly approximates 60 to 75 percent. The pH of distillers condensed solubles is 4.0. The lactic acid content of distillers dried solubles has been reported to be 8 percent (Distillers Feed Research Council, 1970).

Condensed distillers solubles may be marketed in liquid feed supplements for beef cattle (Distillers Feed Research Council, 1970). The microbial stability of the product appears to present little problem. Many find it simpler to market one distillery feed product, thus combining the condensed solubles with wet grains.

### *Distillers Wet Grains with Solubles*

Even modestly sized distillers should seldom consider whole stillage because of the costs involved in transportation, storage, and feeding. Frequently, a better decision would be to separate out the coarse grain fraction from the whole stillage, condense the thin stillage fraction, and then possibly recombine them into one product. Adding the distillers condensed solubles to the wet grains results in a denser product, thus improving storage qualities.

### *Wet Corn Bran*

This by-product is the physically dewatered hulls and fibrous portions of the corn kernel obtained during the wet milling process. It contains about 60 to 65 percent moisture, pH of 4.1, and 13 percent crude protein on a dry matter basis. Because of its rather light, fluffy nature, it spoils and develops pockets of molds rather rapidly. In warm weather it probably should be used up within a few days, and this limits its practical use.

### *Condensed Fermented Corn Extractives*

This by-product is more commonly known as corn steep water and is sometimes referred to as condensed corn steep liquor. It is obtained by the partial removal of water from the liquid that results from steeping corn in a water and sulphur dioxide solution that is allowed to ferment by the action of naturally occurring lactic-acid-producing microorganisms as practiced in the wet milling process.

It is a thick liquid containing about 50 to 60 percent moisture and 46 to 50 percent crude protein on a dry matter basis. A high percentage of the carbohydrates has been fermented to lactic acid. The high lactic acid content along with the presence of some sulphur dioxide provides for a very stable product. The feed may be marketed in liquid feed supplements or in combination with wet corn bran. When marketed as a liquid supplement, problems with crystallization occasionally develop.

### *Wet Corn Gluten Feed*

This feed product contains that part of the corn kernel remaining after extraction of the larger portion of the starch, gluten, and germ by the wet milling process. It generally consists of only the wet corn bran and condensed fermented corn extractives.

The dry matter content approximates 40 percent, of which 22 percent is crude protein. Adding the condensed fermented corn extractives to the wet bran markedly improves the storage qualities of the bran.

### *Distillers Wet Yeast*

This feed product is the surplus yeast produced during ethanol production from starch following wet milling of corn. While little information is available, it probably is similar to spent brewers yeast slurry. The surplus yeast, as produced in the brewery, commonly contains 10 to 14 percent dry matter and 48 percent crude protein on a dry matter basis (Grieve, 1979).

The product can be marketed as a liquid protein supplement suitable for monogastric as well as ruminant animals. However, a problem in practical application of yeast as a liquid protein supplement is the wide variation in crude protein content on an as-fed basis even within the same brewery (Grieve, 1979). The simplest solution is probably to market the distillers wet yeast in combination with wet corn gluten feed as one product or with condensed fermented corn extractives as one liquid supplement.

Research has recently been conducted on the preservation of brewers yeast slurry (Ingledew and Burton, 1979). To be practical as a liquid feedstuff, the yeast slurry must remain stable in composition for at least 2 to 3 weeks of storage. The tendency of the yeast slurry to foam during handling should be eliminated. Ingledew and Burton (1979) showed that preparations of formaldehyde and propionic acid or of formaldehyde, formic, acetic, and propionic acids at a level of 1 percent (volume/weight) were very effective in inhibiting fermentation. Steckley et al. (1979) reported a pH of 5.2 for fresh brewers yeast. Losses in dry matter and true protein were small for material stored at 4°C. However, 13.2 percent and 10.4 percent losses of dry matter occurred over a 35-day period with yeast slurry stored at 21°C and 30°C, respectively. Most of the changes occurred within 2 weeks of storage. Mixtures of formalin, formic, acetic, and propionic acid or to a lesser extent propionic and acetic acid were effective in preserving yeast slurry stored during warm weather.

While data are limited, successful storage and handling systems are in practical use for many feed by-products of conventional distilling or corn wet milling containing higher dry matter levels (e.g., distillers wet grains and condensed fermentation corn extractives). While some problems in this area still exist with these materials, problems are relatively minor. Medium- and even large-sized ethanol distillation plants should consider partial dewatering as a viable alternative to dehydration for marketing feed by-products if located within range of adequate livestock feeding units.

Stillage, either whole or thin, generally should be considered only by small plants in immediate proximity to adequate livestock feeding units. Costs of storing, transporting, and feeding stillage are large. Rapid spoilage in warm weather and freezing in winter are problems. Some risk of lack of supply exists because of plant shutdowns. Furthermore, liquid feeds or feeding systems are foreign to many livestock feeders.

# 4 USE IN ANIMAL FEEDING

## MONOGASTRICS

### *General*

Grain by-products from the distillation industry and corn wet milling have been used at a low level by the feed industry for a number of years. During 1973 to 1979, there was an average yearly production of 1,130,000 metric tons of gluten feed and meal and 385,000 metric tons of distillers dried grains in the United States. This accounted for about 4.6 percent of the total supply of processed feedstuffs available to the livestock industry (U.S. Department of Agriculture, 1980).

Numerous feeding trials have been conducted over the years with the traditional dried or condensed products from wet milling (corn gluten meal, corn gluten feed, corn germ meal, corn steep water) or from distillation of beverage alcohol (distillers dried grains (DDG), distillers dried solubles (DDS), distillers dried grains with solubles (DDGS)). The nutrient content of these products is well known, and when they are used in diets formulated to meet the nutritional needs of swine, poultry, or other animals, they may contribute significantly to the nutrition of the animals. The feeding of wet by-products to swine and poultry has been less extensively studied. While these will reflect the nutrient composition of the dry by-products, they are less well suited for incorporation into traditional diets. Bayley et al. (1971) determined the energy value of by-products from the wet milling of corn with various species of animals. They tested the corn fiber and the corn fiber plus solubles (similar in composition to a commercial corn gluten feed) in comparison to a commercial corn gluten feed. Mean energy values from several studies are presented in Table 4.1.

TABLE 4.1 Energy Value of By-products from Wet Milling of Corn (kcal/g)

| | Metabolizable Energy | | | | Digestible Energy | |
|---|---|---|---|---|---|---|
| Ingredient | Young Chicks | Adult Roosters | Turkey Poults | Turkey Toms | Rats | Swine |
| Corn fiber | 1.14 | 1.24 | 1.02 | 1.34 | 1.46 | 1.73 |
| Corn fiber and solubles | 1.72 | 1.94 | 1.64 | 2.20 | 2.66 | -- |
| Corn gluten feed | 1.86 | 1.77 | 1.63 | 2.08 | 2.39 | 2.63 |

Source: Bayley et al. (1971).

They concluded that the corn fiber plus solubles and the corn gluten feed were not well utilized by chickens, roosters, or young turkeys, but could be a valuable ingredient in diets for turkey breeding stock and swine.

### *Special Considerations*

*Poultry* Matterson et al. (1966) were able to use up to 20 percent DDGS in the diet of laying hens, which supplied one third of the total dietary protein for the hen. Runnels (1966) fed broilers diets containing up to 20 percent DDGS with results comparable to those attained with corn, soybean meal, and fish meal. Potter (1966) reported that the body weights of turkeys fed diets containing 10 and 20 percent DDGS were slightly, but not significantly, increased, whereas feed efficiencies appeared to decrease slightly, as expected, when 10 percent DDGS was present, but decreased greatly when 20 percent was used. In diets with corn gluten meal, a deficiency of lysine was not noted in the diets except in those containing more than 15 percent corn gluten meal.

Runnels (1968) conducted an extensive review concerning high-level use of distillers feeds in diets for various types of poultry. No undesirable effects have been reported from feeding diets containing from 10 to 20 percent DDS or DDGS. In most of the reports, a significant improvement in growth, egg production, feed utilization, and hatchability has been observed in favor of the diets containing the high levels of distillers feeds over the control diets. Scott (1970) has an excellent review of research related to the feeding of distillers by-products to broilers. The reports indicate that the various products, fed in dried form, contribute significantly to proper nutrition of broilers. Harms (1970) has extensively reviewed previous studies on the use of distillers products in diets for laying hens. The papers indicate that DDGS is a satisfactory ingredient for use in diets of commercial layers and broiler breeders when incorporated on the basis of its known nutritional values.

McNab and Shannon (1972) conducted feeding trials in which corn germ meal was included in pelleted chick feeds. They concluded that corn germ meal can be successfully included in broiler feeds at levels up to 20 percent during the first 4 weeks and up to 30 percent during the second 4 weeks. The nitrogen (protein) digestibility of the corn germ meal was 85 percent. Using colostomized laying hens, Hersted (1977) conducted digestibility studies on two different batches of DDS from the production of grain whiskey. For the mean of the two products, the protein digestibility was 47.25 percent, fat digestibility was 82 percent, and the energy value was 2.983 ME kcal/g of dry matter. Jensen (1978) reported that laying hens could be fed up to 20 percent DDGS in isocaloric diets with no adverse effects on egg production or other performance characteristics. Significant improvements in interior egg quality (Haugh units) were observed upon the addition of DDGS. Vandepopuliere et al. (1978) fed laying hens a diet with 43.9 percent distillers dried grains. This diet, although considerably lower in energy, supported egg production as well as the corn-soybean control did. The hens required more feed to produce the eggs and had a smaller size egg, both of these factors reflecting the lower dietary energy.

Misra and Potter (1978) conducted bioassays to determine the availability of various nutrients in a sample of corn gluten meal for poultry. The sample contained 1.085 percent lysine by microbiological analysis, and the available lysine was estimated to be 0.96 percent ± 0.15 percent. It was calculated to contain 4.33 ME kcal/g dry matter.

Corn dried steep liquor concentrate (DSLC) is a blended feed product of fractions obtained from the wet milling of corn. It contains corn germ meal, corn bran, corn gluten meal, and dried condensed fermented corn extractives. Poultry feeding trials at the University of Arkansas (Waldroup et al., 1970; Waldroup and Rutherford, 1971; Waldroup and Hazen, 1979) have shown it to be an acceptable product. In broiler diets an upper limit of 15 percent was suggested, while for laying hens and breeder turkeys up to 20 percent could be effectively utilized. In studies with laying hens, feeding the DSLC resulted in a significant improvement in interior egg quality, especially with older hens. In addition to being a source of known nutrients, corn fermentation condensed solubles have been reported to contain unidentified growth factor activity for broilers and turkeys (Camp et al., 1957; Russo and Heiman, 1959; Russo et al., 1960; Shen et al., 1970; Potter and Shelton, 1978).

*Swine* Peter et al. (1971) conducted studies to determine the metabolizable energy value of DDGS for swine. The mean value reported for four trials was 3.34 ME kcal/g. Yen et al. (1971) examined the use of corn gluten feeds in swine diets. They observed that inefficient use of corn gluten feed by swine was not due to the commonly attributed problems with bulkiness or poor palatability. Rather, it was found to be due to a relatively poor availability of the tryptophan in the corn gluten feed. Sasse and Baker (1973) estimated the availability of the sulphur amino acids in corn gluten meal. They found the total sulphur amino acids to be highly available (98.9 ± 2.1 percent and 99.2 ± 1.6 percent), using two different types of bioassays. Harmon (1974) examined the availability of lysine and tryptophan in DDGS for swine. He reported that with young swine the tryptophan in DDGS was biologically available; however, the young swine were not able to use the lysine in DDGS as efficiently as lysine-HCl. Heavier weight finishing hogs were apparently able to make effective use of the lysine from DDGS.

Harmon (1975) conducted growth trials and balance studies with young pigs to evaluate lysine availability in DDGS. The lysine was efficiently utilized. The DDGS was substituted for up to 20 percent of the diet. Thong et al. (1978) evaluated dietary levels of 0, 17.7, and 44.2 percent DDGS in diets for gestating pigs. All diets were calculated to contain 0.42 percent lysine. Average weight gain during gestation and number and weight of pigs born were similar for all dietary treatments. The authors concluded that DDGS can replace soybean meal on a *lysine-equivalent* basis as a source of supplemental amino acids in diets for gestating swine. It should be noted that the total *protein* content of the diets was increased as the level of DDGS increased. A series of studies was conducted at the University of Illinois (Harmon et al., 1975a,b; Cornelius et al., 1977) on the feeding value for swine of a combined product containing condensed fermented corn extractives, corn germ meal, and corn bran (DSLC). In the first study (Harmon et al., 1975a), DSLC completely replaced all of the soybean meal in diets for growing pigs. Performance was reduced, and the authors concluded that the lysine and tryptophan in the DSLC had limited biological availability. In the second study (Harmon et al., 1975b) the authors concluded that up to 30 percent of the total lysine in the diet for young pigs could be provided from DSLC, while for finishing pigs up to 36 percent of the total lysine could be provided from DSLC. Metabolizable energy of the DSLC was estimated to be 3.79 kcal/g dry matter (Cornelius et al., 1977). This value appears somewhat high, as it exceeds the value normally reported for corn.

Early research on the feeding of wet distillery residue ("distillers slop") conducted in Kentucky (Wilford, 1940) pointed out that very slow gains resulted if distillers slop was fed alone. In addition, carcasses were found to be soft and oily since the concentration of corn oil in the dry matter portion of the residue was increased approximately threefold. Holden (1980) offered to growing pigs (45 to 54 kg) either a self-fed 12 percent corn-soybean meal diet or a limit-fed diet of 1.4 kg of a 12 percent protein supplement with twice-daily access to all the stillage the pigs could consume. No water was provided to the group of animals consuming stillage. Pigs fed the diets with stillage had reduced daily gains. This was primarily because of markedly reduced dry matter consumption for these pigs. The pigs fed the control diet consumed just over 2.72 kg of dry matter per day, while those limit-fed the control diet with free access to stillage consumed just over 1.81 kg per day. Overall feed/gain ratios were fairly similar for the two groups.

Some studies have been conducted with swine to allow some estimates of total water consumption in relation to feed intake. Leitch and Thompson (1944) reviewed studies by several authors in which water/feed ratios of 2.5 or 3:1 for young pigs and 1.5 or 1.75:1 for finishing pigs were recommended. Barber et al. (1963) reported that over the entire feeding period for swine a slurry containing a water/solids ratio of 3:1 gave results comparable to a dry feed, where hogs drank 1.09 kg of water per kilogram of feed when given water *ad libitum*. Holmes and Robinson (1965) reported a water/feed ratio of 3.9:1 for a normal feed, but this was decreased to 2.2:1 when penicillin was added to the diets. Braude and Rowell (1967) reported that hogs fed a 4:1 ratio slurry outperformed those fed a dry feed with water *ad libitum*. The environmental temperature will obviously influence the water/feed ratio. Mount et al.

(1971) fed a dry diet with water *ad libitum*. During a temperature range of 7 to 20°C, the water/feed consumption remained relatively constant at about 2.7:1, but an increase to 30°C increased the ratio to 4.2:1.

*Dogs* McCay et al. (1957) were able to utilize 7 percent distillers solubles in the diet of growing beagle pups with satisfactory weight gains and blood constituents. Beagle bitches produced and weaned satisfactory litters while consuming diets with DDS. Metabolism trials with 7, 15, and 30 percent DDS demonstrated that these levels could be fed without difficulty and dogs did not dislike the diets with 30 percent DDS. Later reports of a breeding trial with 7 percent DDS compared with 7 percent meat scrap demonstrated that conception was excellent, with litter size and weaning rate comparable to those of the meat scrap control (Wanner et al., 1958). At the end of 5 years, no deleterious effects were encountered when corn distillers dried solubles replaced other ingredients (Wanner and McCay, 1960). McCay et al. (1963) confirmed the favorable results of 7 percent DDS in diets for growing beagle pups and with females during reproduction. However, at the 30 percent level of DDS the diets were noticeably less acceptable to the pups, and some cases of mild diarrhea occurred. Corbin et al. (1980) examined the incorporation of distillers dried grains with solubles into dog diets at levels up to 8 percent of the diet. He concluded that DDGS can be successfully incorporated into dog diets without significantly altering the utilization of other dietary nutrients.

*Other Species* Additional data on the feeding value of distillers feeds in diets of horses, fish, mink, and laboratory animals have been summarized by the Distillers Feed Research Council (1970).

## RUMINANTS

### *General*

An understanding of recent developments in ruminant protein metabolism is critical to optimizing the use of ethanol production by-products. Figure 4.1 presents a schematic illustration of protein (nitrogen) utilization by ruminants (Satter et al., 1977). Dietary true protein consumed by the ruminant has two fates in the rumen: (1) degradation by bacterial proteolytic enzymes to amino acids and peptides

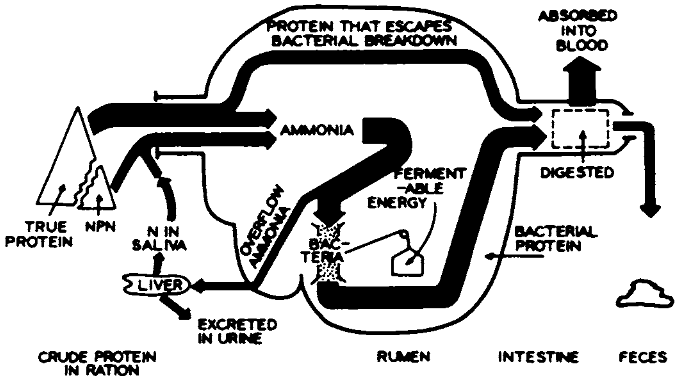


FIGURE 4.1 Schematic illustration of nitrogen utilization by the ruminant. Source: Satter et al. (1977; reprinted with permission of Distillers Feed Research Council).

and deamination to produce ammonia, or (2) escape degradation and flow to the lower digestive tract for digestion by the animal's proteolytic enzymes. Nonprotein nitrogen is readily degraded in the rumen to ammonia, which can be directly incorporated into microbial protein, providing adequate energy and other nutrients are available.

Energy available in the rumen is provided from the digestion of dietary energy components and is necessary for the maintenance and growth of microbial cells. Low-molecular-weight nitrogen compounds (e.g., amino acids, peptides, and ammonia) are used by microbes to synthesize protein in the presence of available energy. Ammonia produced in the rumen and not incorporated into microbial protein represents a net loss of nitrogen to the animal. Furthermore, energy is expended by the animal in removal of excess ammonia.

Protein that escapes the rumen is combined postruminally with microbial protein to meet the amino acid requirements of the animal. Conceptually, as can be seen from Figure 4.1, the ruminant has a digestive system analogous to monogastrics except that all nutrients must pass through a fermentation vat before entering the small intestine. Therefore, the amino acids supplied postruminally are subject to the same constraints normally placed on amino acids in the diets of monogastrics.

True protein that escapes degradation in the rumen is referred to as "bypass protein." The importance of bypass protein in ruminant diets has been reviewed by Chalupa (1975), Clark (1975), and Kempton et al. (1977).

Rounds (1975), Petersen (1977), Waller (1978), and Merchen (1978) have taken an empirical approach, based upon the concepts outlined, to the utilization of bypass protein sources, in combination with urea, to replace soybean meal in ruminant diets. Since a high percentage of the protein in soybean meal (SBM) is degraded in the rumen, a less degradable source of protein such as DDG, DDGS, or corn gluten meal (CGM) could be combined with a 100 percent degradable source such as urea to yield a "new" feedstuff equivalent to SBM in protein characteristics. In a growth study reported by Klopfenstein et al. (1978), calves fed isocaloric and isonitrogenous diets supplemented with a combination of CGM and urea (50:50) gained at the same rate (0.72 versus 0.73 kg/day) as calves fed diets supplemented with SBM. Calves on the urea control (100 percent degradable protein supplement) gained significantly less weight per day (0.57 kg/day). The bypass values reported from similar diets are 62 percent for CGM (Waller, 1978) and 24 percent for SBM (Merchen, 1978). One should have expected equal performance because adequate nitrogen was provided in the rumen for microbial protein synthesis in this study. The calves in this study averaged 227 kg when started on feed. This weight corresponds with the period in the animal's growth curve when protein requirements are high and responses to differences in protein characteristics could be demonstrated. The responses of ruminants fed diets supplemented with bypass proteins and urea are referred to as "complementary" effects (Klopfenstein et al., 1978).

Protein solubility estimates have been used in formulating diets for ruminants (see, e.g., Sniffen and Hoover, 1978). Protein that is degradable in the rumen is also soluble, but protein that is soluble by using various solvents does not represent a complete estimate of the degradable protein present. Protein solubility may provide a good estimate within a feedstuff, but it does not provide an adequate estimate for comparing feedstuffs in formulating diets. The major determinant in protein solubility is the solvent used in the procedure to estimate solubility (Smith et al., 1959; Wohlt et al., 1973). Other factors contributing to solubility of proteins are particle size of the protein source and previous exposure to heat or chemical treatment. The use of solubility estimates in formulating diets for ruminants by the feed industry is an example of the feed industry's striving to incorporate recent concepts of ruminant protein metabolism.

Other approaches have been taken recently by researchers in ruminant protein metabolism to develop systems and methods for estimating protein requirements (amino acid requirements) postruminally and defining protein characteristics important to the ruminant (Burroughs et al., 1974, 1975a, b; Satter and Roffler, 1975; Fox et al., 1977; Kaufmann, 1977; Roy et al., 1977; Bergen et al., 1978; Fox et al., 1979; Waller et al., 1979). The National Research Council has appointed a subcommittee to investigate the protein systems for ruminants.

Ethanol by-products will have their greatest value in cattle diets when they are used as part or all of the supplemental proteins. They may be used as a source of dietary energy in some cases. When used at 0 to 5 percent of the diet, the determined or estimated energy values for corn distillers grains with solubles are higher than for soybean meal, 3.14 versus 2.98 ME Mcal/kg and are about equal to those for corn even though they are relatively higher in fiber content (NRC, 1978). The fiber in the dried grains is considered beneficial in some ruminant diets. Much of the energy reported in corn distillers dried grains with solubles can be accounted for by the high fat content. It is possible that the corn oil could be removed by some process, resulting in a much lower energy product. The total fat content of ruminant diets should be monitored carefully since the NRC (1976) reports that high levels may lower feed consumption.

Since distillers by-product feeds are not considered major supplementary sources of vitamins and minerals for ruminants, much of the research has had a primary objective of evaluating these products as energy and protein sources. Most of the mineral elements are concentrated, compared with the original grains (NRC, 1978). When DDGS is separated into DDG and DDS, the DDS (soluble fraction of DDGS) is usually higher in almost all soluble mineral elements (see Table 2.2). Ethanol by-products can be good sources of minerals for ruminants. The sodium content of certain by-products is higher than would be expected on the basis of feedstock content and reflects the addition of sodium in ethanol production. Other elements such as potassium may be concentrated in the soluble fraction and may be extremely low in the grain fraction of the by-product. The acceptability and palatability of the dry products are excellent based on the amounts cattle will consume when these products are added to diets.

However, there is not an adequate data base at the present time to estimate the feeding value of these products compared with other feeds when included as a major portion of the diet. Therefore, when complete chemical analyses and animal feeding trial data on a by-product are available and metabolizable energy values have been determined, conventional linear programming techniques can be used to determine the potential value of the product in a given diet formulation.

*Special Considerations*

*Lactating Dairy Cows* Warner (1970) reviewed the status of distillers by-products as feed for lactating dairy cows, and the only additional data reported since that time are related to protein and fat metabolism. Early research conducted prior to the mid-1940's generally reported increased milk production when dried distillers grains were added to the diet. Dairy farmers have been, and still are, enthusiastic about the acceptability and productive capabilities of distillers feeds.

In a series of experiments at Cornell (Loosli and Warner, 1953; Loosli et al., 1952; Warner et al., 1957; Loosli and Warner, 1958; Loosli et al., 1960; Loosli et al., 1961), DDG, DDGS, and DDS were compared with each other and other sources of protein. In all studies, the distillers by-products were at least equal to and were sometimes slightly superior to other sources of protein. The evaluations were based on milk production and in some cases milk fat content. The research would rank the by-products in the following order: DDG, DDGS, and DDS. Corn and milo grains were considered equal, and corn grains were superior to rye grains. Subsequent research on protein solubility and degradability (Sniffen and Hoover, 1978) suggests that some of the differences between the distillers by-products and other sources of protein are due to the lower solubility of distillers by-products. Since solubles are more highly degradable, this factor could explain the relative rankings of the three different by-products. The improvement in milk fat content when DDGS was added to diets may be due to the higher content of fat in this product (Palmquist, 1978).

Most of the information available on the use of wet distillers by-products for lactating dairy cows is based on observations rather than well-controlled research. The amount of water is considered one limiting factor; however, the high-producing dairy cow has a high water requirement, which may make her a good candidate for some of these products.

*Young Calves* Distillers by-products have been fed to dairy calves in both milk replacers and in calf starters. A review of the studies (Warner, 1970) on the use of DDS as a substitute for other ingredients in milk replacers generally revealed a linear decrease in growth rate of calves when this source of nutrients replaced the commonly used milk products. Current economic conditions would not project a bright future for these products in milk replacers.

The potential use of distillers by-products in calf starters is somewhat more encouraging. Warner (1970) reviewed the use of both DDG and DDGS as replacements for much of the protein in calf starter diets (generally up to 16 weeks of age). Warner reported that when used at up to 20 percent of the dry feed, DDS and DDGS resulted in excellent growth. When 50 percent of the starter was in the form of DDS, consumption was reduced; however, 35 percent DDS resulted in a normal growth rate.

*Growing Cattle* Beef cattle between weaning and 270 to 320 kg are termed "growing" cattle. Growing cattle are typically fed diets medium to low in energy and require supplemental protein if low-protein forages, such as corn silage, are fed. The protein requirement, for a given rate of growth, is higher during this time than at any other time after weaning. Most research evaluating the role of DDGS, DDG, CGM, and corn distillers solubles (CDS) has been conducted by using growing cattle.

Research reported by Klopfenstein et al. (1978) indicates that combinations of DDG or DDGS with urea have a complementary effect in meeting the protein requirement; urea supplies the microbial protein, and DDG or DDGS supplies the bypass protein. Cattle fed combinations of dried distillers feeds plus urea performed equally as well as those fed soybean-meal-supplemented diets. The protein in the distillers feeds was used more efficiently than that in soybean meal.

The complementary effect of DDGS and anhydrous-ammonia-treated corn silage was investigated by Waller et al. (1980). The performance of growing steer calves fed 11 percent protein, anhydrous-ammonia-treated corn silage and DDGS was equivalent to that of calves fed normal silage and soybean meal. The results of this trial and trials reported by Klopfenstein et al. (1978) indicate that DDG and DDGS are good sources of bypass protein for growing beef cattle. The magnitude of response noted is directly linked to maximizing microbial protein synthesis in the rumen plus supplementation of this microbial protein with a bypass protein.

Condensed distillers solubles (CDS) have been used in diets for growing cattle to supply "urea-protein factors" or as "natural protein" in liquid supplements. It has been suggested that the presence of unidentified factors is associated with the method of processing CDS (Beeson, 1975). Klopfenstein et al. (1976) found that calves receiving CDS as a supplemental protein source had performance similar to that of urea controls and that CDS has no bypass protein. CDS is usually marketed as a fraction of DDGS. The effect of drying CDS on DDG to form DDGS has been shown to be slightly positive (Klopfenstein et al., 1976). Additional information on feeding values of DDG, DDGS, and CDS has been published by the Distillers Feed Research Council (1970), Horn and Beeson (1969), Brethour (1974), and Sniffen and Hoover (1978).

Corn gluten meal is a by-product when corn is wet milled prior to the separation of starch for ethanol production. Research reported by Petersen and Klopfenstein (1977) and Merchen (1978) indicates that CGM has protein characteristics that are similar to those found in DDG. Complementary effects were reported between CGM and urea in diets for growing cattle.

*Finishing Cattle* The nutrient requirements for finishing cattle usually dictate that diets be high in energy and moderate in crude protein, i.e., 9.75 to 12.7 percent, on a dry matter basis (NRC, 1976). Ethanol production by-products can be used as partial or complete replacement of the supplemental protein by inclusion on a dry matter basis for up to about 10 percent of the diet.

Schindler and Farlin (1980) reported on a cattle feeding study in which corn gluten meal, and a combination corn gluten meal and urea were compared to urea as protein supplements. The performance of these cattle, averaging 266 kg, was not significantly affected by the source of supplemental protein. This would indicate that in diets fed at normal finishing weight ethanol by-products compete with urea rather than soybean meal.

In a feeding trial reported by Ward and Matsushima (1980), dried distillers grains were used in a finishing trial at 0, 15, and 30 percent of the dry matter. This trial was conducted to evaluate the replacement value of

DDG as an energy source in feedlot diets. No significant difference in performance was noted as a result of DDG in the diets. The value of DDG in the diet was estimated at $103/mt at the 30 percent level in comparison with $136/mt, which was the market value at the time of the experiment. Therefore, when ethanol by-products such as DDG are used as an energy source, the value of the by-product is significantly lower than its value as a protein source.

In many cases the option exists to use high-moisture products in feedlot diets. At each feedlot the constraints imposed by the feed-mixing system, the feed delivery system, and the bunker design are likely to be unique and may impose a limit on the amount of high-moisture material that may be added to the diet.

The amount of extra moisture that may be added to the diet of finishing cattle is also limited by the amount of moisture that may be added without reducing rate of gain. While the ratios of water to dry matter intake have been reported from a number of sources, excessively wet feedlot diets often suppress dry matter intake (Winchester and Morris, 1956). Lake (1976) reported that high-moisture feeds reduce bunker life of feedlot diets and necessitate the consumption of feed within about 12 hours since out-of-condition feed will reduce cattle performance. The use of liquid feeds, such as stillage, is limited by the amount of material that may be absorbed or held on the remaining diet without running out of the bunker or separating from the feeds. If these products are to be used as the protein supplements, it is essential that feed-mixing control be maintained.

Reported energy values for the grain distillers by-products appear to be quite high in relation to those of the commonly fed cereal grains (NRC, 1976). However, most of these values were determined or estimated by including a very small part of the product in the diet. It is unknown whether animal performance would be affected if diets were formulated using a higher percentage of these products in the event that distillers by-products were priced below grains. It may be safe to assume that the reported energy values will overestimate the value of grain distillers by-products as energy feeds.

Nonfeed costs in finishing cattle typically range from 30 to 50 cents per head per day in commercial lots. Therefore, any dietary change that reduces the rate of gain may be quite expensive, and the feedstuffs causing this loss in performance will be discounted (Church, 1980).

*Mature Cattle at Low Production* Cattle in this classification can utilize a wider range of feedstuffs and can consume higher quantities of low-digestibility feeds than rapidly growing or lactating animals. Large amounts of valuable distillers dried by-products would normally not be recommended for this class of animals, since for most animals in a low-production status the only supplemental nutrients needed are protein, energy, phosphorus, trace minerals and vitamin A. Liquid feed supplements are used in many areas to provide supplemental nutrients for wintering beef or dairy cows in maintenance programs. Liquid distillers by-products have shown promise in terms of improving performance with conventional liquid feeds (Lusby and Howell, 1980). These liquid by-products could also be used to reconstitute poor quality forages or crop residues for use as feedstuffs for low-producing animals.

*Sheep and Goats* Most of the recommendations for sheep and goats have been extrapolated from studies with cattle. Sheep have been used as a model for studies of distillers by-products on nitrogen metabolism (Ely et al., 1975). In general, a combination of distillers dried solubles with urea in high-roughage diets increases cellulose digestion. It can be assumed that sheep and goats would utilize distillers by-products to about the same extent as cattle.

# 5 HEALTH, SAFETY, AND REGULATORY CONSIDERATIONS

## CONTAMINANTS

### *Heavy Metals*

The presence of heavy metals in ethanol production by-products would be linked to the materials used on construction of the ethanol production plant or contamination of the feedstocks prior to the production of ethanol. Plant designs that use recycled flue gas to dry the by-products may be considered suspect in the contamination of by-products unless the gas is cleaned prior to use. Containers used for the storage of high-moisture by-products should be made of materials that would not be affected by acids and possibly release contaminants.

### *Pesticides and Herbicides*

Pesticides used to treat grains or contaminating grains prior to fermentation will likely be present in some of the by-products. The chlorinated hydrocarbons and chemical contaminants such as polychlorinated biphenyls and polybrominated biphenyls would be expected to contaminate the feed by-products. Chemicals that are highly volatile would be removed either in the cooking or the distilling phase of the manufacturing process.

### *Mycotoxins*

Portions of the grain crop are contaminated each year by molds such as those of the genus *Aspergillus* that produce aflatoxin. These grains may serve as a potential substrate for the production of ethanol, but research studies have demonstrated that the mold toxins remain in the residual grain and are concentrated, on a dry matter basis, because of the removal of the starch through fermentation.

Bennett and Anderson (1978) conducted a review of studies related to the distribution of aflatoxin and zearalenone in wet-milled corn products. They found that mycotoxins present in the corn feedstock were concentrated in the residual by-products generally used for animal feed. Over 97 percent of the aflatoxin contained in the original corn sample was accounted for in the by-products, and more than 99 percent of the zearalenone was recovered in the by-product. Although it has been demonstrated that the aflatoxin in corn can be decontaminated by treatment with ammonia, there is no proven process for the removal or destruction of zearalenone in corn.

Lillehoj et al. (1979) used corn that was naturally contaminated with aflatoxin as a substrate in the fermentation of ethanol. Distribution of the toxins in several processes and recovery fractions were identified. Only low levels of the mycotoxin appeared in the distilled ethanol. The toxin accumulated in the spent grains and solubles. There appeared to be little toxin degradation during ethanol fermentation.

Dam et al. (1977) inoculated grains (corn, wheat, and corn-milo substrates) with aflatoxin before cooking and ethanol fermentation. They reported that, through processes involved in the isolation of a high-protein concentrate from the distillers residue, there was destruction of some aflatoxins in excess of 90 percent.

## HAZARDS

### *Animal Health*

The by-products produced by the beverage alcohol industry have been used for years with no major animal-health-related problem. However, with the high-moisture by-products the potential for microbial contamination does exist before feeding.

### *Residues in Edible Products*

With products from the beverage alcohol industry, residues have not been a problem. With the production of alcohol for fuel, the option exists to use substrates not safe or suitable for animal feeds. Residues can become a serious problem in animal production for two reasons. First, any residue in the feedstock is likely to be concentrated approximately 3 times in the by-products. Second, the risk of contaminated feedstock being used for fuel ethanol production is much higher than in the beverage industry. Toxins or hazardous residues in the substrate will have to be monitored carefully by both the producers and the users of the by-products for possible toxic effects.

### *Nutrient Imbalance*

As with any other feedstuff, the nutrient content of ethanol production by-products must be considered in balancing diets. If used as the primary ingredient, a deficiency of calcium and potassium could occur with either the DDG or the DDGS. While the need to supplement with calcium is probably recognized, the deficiency of potassium might surprise those who assume this element is not a problem in practical diet. The low fiber content and buffering capacity of ethanol by-products could induce acidosis in cattle. This would be more critical if the palatability of the product is variable, such as it would be if wet stillage is fed to cattle.

### *Regulatory Aspects*

Ethanol producers wishing to sell by-products for feed use will be required to register the feed in the state(s) in which it is sold. A registration fee ranging from 5 to 25 cents per ton sold will have to be paid, depending on state requirement. Dry products will likely have to carry a tag guaranteeing minimum crude protein, fat, and maximum crude fiber and the name of the original substrate. Wet products will also have to guarantee not to exceed a maximum moisture. Feed definitions from the Association of American Feed Control Officials for the production of ethanol for gasohol have not as yet been proposed.

It is unlikely that ethanol producers will be able to sell by-products using the standard beverage alcohol definitions in most states unless they buy the same food grade feedstocks and use very similar processes. The potential for heat-damaged proteins, which exists in ethanol production, may require that these feed products be tested for heat damage and that damage be declared on the tag.

Samples of ethanol production by-products should be pulled and monitored for mold toxins, pesticides, insecticides, and other residues.

Ethanol producers should recognize that the purpose of state feed control regulations is to aid both the buyer and the seller and to protect the public from possible harmful substances carried into the food chain by animal feeds. The buyer of any livestock or poultry feed or ingredient has the right to be sure the commodity purchased meets or exceeds the minimum guarantees implied by the name or by the tag specifications.

Many potentially different products resulting from fuel ethanol production will give producers, buyers, and feed regulatory officials problems, because their nutritional value is unknown. Products that vary in consistency will not be easy to move in commerce. Some producers may find that it may be illegal to sell some products in certain states.

The Federal Food and Drug Administration has the responsibility to protect the food chain from possible hazardous materials. Waste product disposal and or excessive urine or fecal output of animals resulting from very high moisture products may cause the users of some by-products to come under existing or new regulations administered by either the state or the federal environmental protection agencies.

Wet products that attract flies or create odor problems at feeding facilities may already be restricted by legislation.

# 6 HIGH-PRIORITY RESEARCH NEEDS

The focus of these research priorities is to create a data base on the feeding value of ethanol production by-products. This data base will be used by ethanol producers as guidelines for planning ethanol production facilities. Also, feed manufacturers, livestock nutritionists, and producers need the data to make better decisions on feed formulation and feeding practices that would optimize the use of ethanol production by-products.

The high-priority research needs identified by this task force are presented by chapter headings. All of these research needs are of high priority; therefore, ranking within a chapter does not indicate order of priority.

## ETHANOL PRODUCTION AND BY-PRODUCT RECOVERY

### *Reducing Moisture Level of Ethanol Production By-products*

Developing efficient methods for reducing the moisture content of ethanol production by-products is crucial to the widespread use of by-product and economic viability of ethanol production facilities. Without moisture removal, the by-product is too dilute (93 to 94 percent moisture) to have widespread applicability as a feedstuff. A drier product extends the storage time and reduces the cost for handling and transporting the by-product. Research is needed on modifying the ethanol production process to yield a lower-moisture-content by-product. Process modifications may include using less water in the process or recycling stillage to reduce freshwater use. Additional benefits include reduction in the amount of heat (energy) required in the production process. Also, the effect of different feedstock processing methods (e.g., wet milling and micronizing) on by-product moisture content should be evaluated.

Methods for dewatering the by-products are also necessary since process modifications may reduce the moisture content only to about 90 percent. The performance characteristics of various dewatering devices (e.g., screens, presses, vacuum filters, centrifuges, and ultrafilters/reverse osmosis) should be evaluated for various potential by-products. Also the effects of using filter aids, coagulants, and polyelectrolytes to improve the capture efficiency of the above-mentioned dewatering devices, and the potential adverse effects these aids may have on animal performance should be evaluated.

These dewatering devices will generally dewater the product to 65 to 75 percent moisture. These products must be dried or condensed if the moisture content is to be reduced further. Efficient and economical driers and evaporators should be developed and/or evaluated.

## CHARACTERISTICS OF ETHANOL PRODUCTION BY-PRODUCTS

### *Nutritional Value of Ethanol By-products*

A number of factors affect the potential nutritional value of ethanol production by-products. The first consideration is the feedstock itself. Research should include studies to characterize the nutritional value of by-products from the economically important feedstocks.

An example of research studies needed in feedstock evaluation is the investigation of high-moisture grain as a feedstock for ethanol production. Because the high-moisture grain has undergone fermentation in storage prior to ethanol production, the potential by-products produced from this feedstock should differ from by-products produced from dry corn as a feedstock.

There are many potential variations in the ethanol production process. Thus it will be necessary to evaluate the effect of removing the by-product at different stages of the production process (i.e., after saccharification, after fermentation, and after distillation) on nutritional value. Studies are also necessary to evaluate the relationships of ethanol yields to the nutritive value of by-products.

Studies are needed to evaluate the protein values of ethanol production by-products as protein sources. Particular emphasis will need to be placed on rumen degradability and availability of amino acids.

The energy values of these products should be determined at different levels of inclusion in the diet. There is a need for metabolizable energy values and estimates of the net energy values for maintenance, growth and fattening, and lactation. Research to determine the content and availability of certain minerals, particularly phosphorus, potassium, and sodium is recommended.

### *Evaluation of Physical Characteristics of By-products*

The by-products increasingly may be fed in the wet form, with variable amounts of moisture. The physical characteristics will determine the type of equipment needed to handle, store, and feed the by-products. More information is needed on the physical characteristics of by-products (e.g., bulk density, particle-size distribution, flow characteristics, and freezing point). These characteristics should be measured on products from ethanol production by using different processes and different feedstocks.

Equipment should be designed to handle the by-products from various size ethanol plants for efficient handling of the products in different feeding systems. Different components of the equipment should be tested and modified to optimize operation efficiency.

## STORAGE AND HANDLING OF ETHANOL BY-PRODUCTS

### *Increasing Stability in Storage or Feed Bunker*

Several by-products in the wet form decompose rapidly, especially during warm weather and on exposure to air. Information is needed on the rate of deterioration of by-products as influenced by various factors such as temperature, moisture level, combination with other ingredients, and exposure to air. A major problem exists with feeding stillage since it must be used within 1 to 2 days in warm weather, and fed twice daily to prevent spoilage in feed bunkers. Frequent interruption of supply will drastically reduce animal performance and decrease the utility of stillage as a feedstuff. Research is needed on the use of preservatives (e.g., propionic acid and formaldehyde) for improving the storage stability of stillage. The research should include ensiling of the products alone and with other ingredients, and prevention of spoilage in the feed bunker.

## USE IN ANIMAL FEEDING

### *Use of Ethanol Production By-products in Animal Feeding*

While a considerable amount of information has been compiled on the use of dried ethanol production by-products in animal diets as supplementary sources of nutrients, data on the use of wet by-products and high levels of both wet and dry products are not definitive for livestock performance. Additional information is needed on the effect of moisture content of the by-products on nutrient intake. Data are needed on the maximum amount of the by-products that can be incorporated into a diet without depressing animal performance below optimum economical levels.

Research should be conducted on the factors that contribute to depressed or enhanced performance of animals when ethanol by-products are fed at different levels. Health problems such as acidosis and laminitis may occur in the feeding of high levels of by-products and should be investigated. The development of feeding systems to optimize the use of ethanol production by-products, including systems analysis and economic evaluation, will be needed if large amounts of the by-products become available. Also, feeding high levels of wet by-products may change waste management practices.

### *Investigating Different Systems for Feeding High-Moisture By-products*

Ethanol production by-products have been used under a variety of feeding systems for ruminants, swine, and poultry. However, most of the research and practical feeding has been with dehydrated materials. The feasibility of using the high-moisture by-products in different feeding systems for different classes of animals should be investigated. The research should include feeding at different moisture levels (e.g., slurry and gruel) with poultry, swine, beef cattle, dairy cattle, sheep, fish, and other animals. For some systems, the by-products should be fed separately, whereas for others they should be blended with other ingredients.

## HEALTH, SAFETY, AND REGULATORY CONSIDERATIONS

### *Contaminants and Health Hazards*

The major contaminants and health hazards that might occur in feedstuffs resulting from ethanol production using conventional feedstocks are not considered to be of high research priority. If significant quantities of feedstock contaminated with a specific compound are available, such as seed corn, research directed toward deactivation of the contamination in the by-product may be justified.

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# APPENDIX A

## GLOSSARY

*Azeotrope* is a term for two liquids that, at a certain concentration, boil at the same temperature. Ethanol and water cannot be separated further than 194.4 proof (97.2 percent ethanol) because at this concentration ethanol and water form an azeotrope and vaporize together.

*Azeotropic distillation* refers to the distillation in which a substance is added to the mixture to be separated in order to form an azeotropic mixture with one or more of the components of the original mixture; the azeotrope formed will have a different boiling point from that of the original mixture, which will allow separation to occur.

*Beer* refers to the fermented mash that contains about 11 to 12 percent ethanol; it usually refers to the ethanol solution remaining after yeast fermentation of sugars.

*Beer column* (stripping column) refers to the section of a distillation column where the ethanol is stripped from the beer.

*By-product* refers to any product (excluding ethanol) from the ethanol production process that has value as a feedstuff.

*Clarification* refers to the process of separating suspended material from solution, leaving a relatively clear solution.

*Condensed distillers solubles* are obtained after the removal of ethanol by distillation from the yeast fermentation of simple sugars obtained usually from a grain or mixture of grains by condensing the thin stillage fraction to a semisolid.

*Condensed fermented corn extractives* are obtained by the partial removal of water from the liquid resulting from steeping corn in a water and sulphur dioxide solution that is allowed to ferment by the action of naturally occurring lactic-acid-producing microorganisms as practiced in the wet milling of corn.

*Distillation* refers to the process of separating components of a mixture by differences in boiling point.

*Distillers wet grains* are obtained after the removal of ethanol by distillation from the yeast fermentation of a grain or a mixture of grains by separating the resultant coarse grain fraction by centrifugation, screening, or processing.

*Distillers wet grains with solubles* are obtained by combining distillers wet grains and condensed distillers solubles such that at least three quarters of the solids of the whole stillage are contained.

*Distillers wet yeast* is the surplus yeast produced during ethanol production from starch following wet milling of corn.

*Feedstock* refers to any material used to supply starch or glucose in the production of ethanol.

*Mash* refers to the mixture of grain and other ingredients with water that passes the saccharification process.

*Rectifying column* refers to the section of distillation column above the feed tray in which rising vapor is enriched by interaction with a countercurrent falling steam of condensed vapor.

*Saccharification* refers to the process (cooking, pH adjustment, enzyme addition) involved in converting complex carbohydrates into simple fermentable sugars, such as glucose or maltose.

*Thin stillage* is the material remaining after separating distillers wet grains from the whole stillage.

*Wet corn bran* is the physically dewatered hulls and fibrous portions of the corn kernel obtained during the wet milling process.

*Wet corn gluten feed* is that part of the corn kernel remaining after extraction of the larger portion of the starch, gluten, and germ by the wet milling process. It generally consists of only the wet corn bran and condensed fermented corn extractives.

*Wet milling* refers to the processing of grain to separate the grain into germ, gluten, and starch fractions.

*Whole stillage* refers to the unprocessed product obtained after the removal of ethanol by distillation from the yeast fermentation of simple sugars obtained, usually from a grain or mixture of grains.

## APPENDIX B
## RECOMMENDED PURCHASING GUIDELINES FOR ETHANOL BY-PRODUCTS
(American Feed Manufacturers Association, 1980)

### CORN GLUTEN MEAL 60%

*Product Description*

Corn Gluten Meal (60%) is the dried residue from corn after the removal of the larger part of the starch and germ, and the separation of the bran by the process employed in the wet milling manufacture of corn starch or syrup, or by enzymatic treatment of the endosperm. It may contain fermented corn extractives and/or corn germ meal.

*Typical Analysis*

| | |
|---|---|
| Protein | 60%-65% |
| Fat | 1%-5% |
| Fiber | 0.5%-2.5% |
| Xanthophyll | 125-200 mg per lb. |
| Moisture (Maximum) | 13% |

*Factors Influencing Quality*

Composition of corn being processed as well as the individual plant processing equipment and wet milling process used.

*Physical Properties*

Bulk Density (pounds per cubic foot): 33-36.
Color: Golden yellow.

Odor: Characteristic fresh, slightly pungent cereal feed--not sour, musty, rancid or otherwise undesirable.

Texture: Uniform composition, grind and color throughout the lot.

Screen Analysis: Variable. (8% to pass through U.S. No. 10 screen).

*Availability*

Generally available but supply may be limited in some areas.

*Feed Applications*

May be used as a protein source in poultry, livestock rations, and pet foods. Serves as a good source of Xanthophyll for use in broiler and roaster type rations, and for yolk color in layer rations.

## CORN GLUTEN MEAL 41%

*Product Description*

Corn Gluten Meal (41%) is the dried residue from corn after the removal of the larger portion of the starch and germ, and the separation of the bran by the process employed in the wet milling manufacture of corn starch or syrup, or by enzymatic treatment of the endosperm. It may contain Fermented Corn Extractives and/or corn germ meal.

*Typical Analysis*

| | |
|---|---|
| Protein | 41%-43% |
| Fat | 1%-2.5% |
| Fiber | 4%-6% |
| Xanthophyll | 63-100 mg. per lb. |
| Moisture (Maximum) | 11% |

*Factors Influencing Quality*

Composition of the corn being processed as well as the individual plant processing and milling system used.

*Physical Properties*

Bulk Density (pounds per cubic foot): 30-36.
Color: Variable--golden to brownish yellow.
Odor: Characteristic processed fresh cereal odor--not moldy, sour, rancid or otherwise undesirable.
Texture: Granular.
Screen Analysis: Variable.

*Availability*

Availability limited to a few suppliers.

*Feed Applications*

Commonly used as a protein source in swine and ruminant feeds, and pet foods; also as a pigmentation factor source in poultry feeds.

## CORN GLUTEN FEED

*Product Description*

Corn Gluten Feed is that part of commercial shelled corn that remains after the extraction of the larger portion of the starch, gluten, and germ by the process employed in the wet milling manufacture of corn starch or syrup. It may or may not contain fermented corn extractives and/or corn germ meal.

*Typical Analysis*

| | |
|---|---|
| Protein | 25% |
| Fat | 3.5% |
| Fiber | 6.6-10% |
| Moisture (Maximum) | 11% |
| pH | 4-4.5 |

*Factors Influencing Quality*

Composition of the corn being processed as well as individual plant processing equipment and wet milling system used.

*Physical Properties*

Bulk Density (pounds per cubic foot): 25-37.

Color: Light to dark brown.

Odor: Characteristic gluten feed odor--fresh coffee-like odor, not sour, musty, burnt or otherwise undesirable.

Uniformity: The product shall be free-flowing and uniform with respect to composition and grind throughout the lot.

Screen Analysis: Variable.

*Availability*

Production is uniform throughout the year. However, there is seasonable variation in demand.

*Feed Applications*

Corn Gluten Feed is commonly used as a medium level protein source. It may be used in poultry (replacement chicks, layer, and breeder), turkey, swine, horse, and ruminant feeds, and pet foods.

## CORN GERM MEAL

*Product Description*

Corn Germ Meal (wet milled) is ground corn germ from which most of the solubles have been removed by steeping and most of the oil removed by hydraulic, expeller or solvent extraction processes, and is obtained in the wet milling process of manufacture of corn starch, corn syrup and other corn products.

*Typical Analysis*

| | |
|---|---|
| Protein | 20.0% |
| Fat | 0.5% |
| Fiber | 11.0% |
| Moisture | 11.0% |

The above analysis is applicable for solvent extracted meal. The oil content will be higher for screw or hydraulic press meal.

*Factors Influencing Quality*

Composition of the corn being ground as well as the individual plant processing equipment used.

*Physical Properties*

Bulk Density (pounds per cubic foot): 24-28.
Color: Light buff.
Odor: Characteristic fresh cereal--not sour, musty, rancid or otherwise undesirable.
Texture: Fine to medium grind--product to be uniform in composition and color throughout the lot.
Screen Analysis: 95% through U.S. No. 10 screen.

*Availability*

Generally available but supply is limited.

*Feed Applications*

May be used for most feed applications.

DRIED STEEP LIQUOR CONCENTRATE

*Product Description*

Condensed Fermented Corn Extractives dried on the germ meal and bran that remains after the extraction of the larger portion of the starch, bran, gluten and oil by the process employed in the wet milling manufacture of corn starch or syrup. It may contain Corn Gluten Meal to adjust protein content.

*Typical Analysis*

| | |
|---|---|
| Protein | 30-33% |
| Fat | 1.5% |
| Fiber | 4-6.5% |
| pH | 4-5 |

*Factors Influencing Quality*

Composition of the corn being processed as well as individual plant processing equipment and wet milling system used.

*Physical Properties*

Bulk Density (pounds per cubic foot): 36.
Color: Light to golden brown.
Odor: Characteristic gluten feed odor--not sour, musty, burnt or otherwise undesirable.
Uniformity: The product shall be free-flowing and uniform with respect to composition, granulation and color.
Texture: Granular.

*Availability*

Production is uniform throughout the year.

*Feed Applications*

May be used in poultry, swine and ruminant feeds.

SORGHUM GLUTEN MEAL

*Product Description*

Sorghum Gluten Meal is that part of commercial sorghum grains that remains after the extraction of the larger part of the starch and germ, and the separation of the bran by the processes employed in the wet milling manufacture of starch or syrup.

*Typical Analysis*

| Nutrient | Expect % | (Range %) |
|---|---|---|
| Moisture | 7.0 | (6.0-10.0) |
| Protein | 42.0 | (41.0-44.0) |
| Fat | 4.0 | (3.0-5.5) |
| Fiber | 4.0 | (2.5-5.5) |

| | | |
|---|---|---|
| Ash | 2.0 | (1.5-3.0) |
| Ca | 0.05 | (0.02-0.07) |
| P | 0.30 | (0.2-0.4) |

*Physical Properties*

Color: Grayish tan to tan.
Odor: Wood-like odor.
Texture: Very fine and dusty. 80% passes a #20 screen and 20% passes a #60 screen.
Test Weight: Expected--27 lbs./cu.ft.
Range--27 lbs. to 32 lbs./cu.ft.

SORGHUM GLUTEN FEED

*Product Description*

Sorghum Gluten Feed is that part of commercial sorghum grains that remains after the extraction of the larger part of the starch and germ by the processes employed in the wet milling manufacture of starch or syrup.

*Typical Analysis*

| Nutrient | Expect % | (Range %) |
|---|---|---|
| Moisture | 7.0 | (6.0-10.0) |
| Protein | 24.0 | (22.5-26.0) |
| Fat | 3.0 | (2.0-5.0) |
| Fiber | 7.0 | (6.5-9.0) |
| Ash | 6.5 | (4.5-6.5) |
| Ca | 0.15 | (0.10-0.20) |
| P | 0.70 | (0.5-0.8) |

*Physical Properties*

Color: Reddish brown to brown.
Odor: Similar to corn gluten feed, but not so pungent.
Texture: 100% passes a #8 screen and 90% passes a #16 screen.
Test Weight: Expected--29 lbs./cu.ft.
Range--27 lbs. to 33 lbs./cu.ft.

# CORN DISTILLERS DRIED GRAINS

*Product Description*

Corn Distillers Dried Grains is the product obtained in the manufacture of alcohol and distilled liquors from corn, or from a grain mixture in which corn predominates, by drying that portion of the whole stillage retained by screens. Grain Sorghum Distillers Dried Grains follow the same definition except that "Grain Sorghum" replaced "Corn."

*Typical Analysis*

| Nutrient | Expect % | (Range %) |
|---|---|---|
| Moisture | 11.0 | (8.5-12.0) |
| Protein | 26.0 | (24.0-28.0) |
| Fat | 8.5 | (7.0-9.5) |
| Fiber | 11.0 | (10.0-12.5) |
| Ash | 3.5 | (3.0-6.0) |
| Ca | 0.15 | (0.03-0.40) |
| P | 0.60 | (0.30-0.75) |

*Physical Properties*

Color: Brown to dark brown.

Odor and/or Taste: Distinctive, sharp odor, characteristic of dried fermented grains. Smells slightly toasted and malt-like.

Texture: Production of this ingredient from different manufacturers varies widely in texture (bulk and texture are roughly comparative--see range of Test Weight) depending on the grind and the percentage of distillers solubles (see under Miscellaneous Information). Coarse grains contain as much as 2 to 3% of ball-like particles which are retained on a #6 screen and as much as 20% on a #10 screen. Certain grinds of Distillers Grains will all pass a #8 screen. A high percentage of dried distillers solubles is desirable as is evidenced by higher protein; also by darker color and/or ball-like particles. Excessive fibrous material (Corn, Bran, etc.) is objectionable. Such grains are lighter in color, lower in protein and higher in fiber.

Test Weight: Expected--19 lbs./cu.ft.
Range--18 lbs./cu.ft.

Miscellaneous Information: There are three types of Distillers Dried Grains: Dark Heavy, Medium Dark and Light. The most desirable type is the Dark Heavy Grains which contain the highest percentage of dried distillers solubles. The presence and/or size of ball-like particles (solubles) depends on whether the solubles were sprayed into the grains before drying or merely mixed in. Light grains are those which are sold without the dried solubles, the latter being processed and sold separately.

## CORN DISTILLERS DRIED SOLUBLES

### *Product Description*

Corn Distillers Dried Solubles is the dried clarified stillage from a yeast fermented grain-salt mash, in which corn predominates, after the grain residues have been removed by screening and centrifuging.

### *Typical Analysis*

| Nutrient | Expect % | (Range %) |
|---|---|---|
| Moisture | 8.0 | (7.0-12.0) |
| Protein | 26.0 | (24.0-27.0) |
| Fat | 9.0 | (7.0-10.0) |
| Fiber | 4.0 | (2.50-5.5) |
| Ash | 8.0 | (6.0-9.0) |
| Ca | 0.30 | (0.15-0.40) |
| P | 1.20 | (1.00-1.40) |

### *Physical Properties*

Color: Medium brown to dark brown.

Odor and/or Taste: Pleasant, distinctive odor, characteristic of dried fermented grains. It smells slightly toasted and malt-like. The moderately acid taste of the product is due to the presence of lactic acid.

Texture: Fine flaky product. 80-90% passes a #12 screen.

Test Weight: Expected--26 lbs./cu.ft.
Range--25 lbs./cu.ft.

## CORN DISTILLERS DRIED GRAINS WITH SOLUBLES

### *Product Description*

Corn Distillers Dried Grains with Solubles is the product obtained after the removal of ethanol by distillation from the yeast fermentation of the grain by condensing and drying the resultant whole stillage. The coarse fibrous material is separated from the soluble and finely suspended portion by screening or centrifuging. The liquid fraction is concentrated by evaporation to a syrup which is combined with the coarse fibrous fraction and dried in either steam tube or heated air driers.

### *Typical Analysis*

| | |
|---|---|
| Protein | 26.5-27.0% |
| Fat | 7.0-8.0% |
| Fiber | 8.5-9.5% |
| Moisture | 9.0-12.0% |
| Ash | 4.5-5.0% |

### *Factors Affecting Quality*

The composition of Corn Distillers Dried Grains with Solubles is determined mainly by the grain formula and composition of the grains used in the fermentation process. Processing variables such as fineness of grind of cereal grains, cooking procedures, fermentation time and pH, and drying equipment all can have an influence on nutrient composition. In general, the composition of distillers dried grains with solubles is approximately three times that of the cereal grains used (plus vitamins and other metabolites formed by yeast cells during fermentation). Corn Distillers Dried Grains with Solubles with uniform moisture (8-12%), properly cooled and stored in a cool location will withstand long periods of storage. Occasional moving or circulation is recommended to maintain uniform moisture content. When stored under warm, humid or uneven temperature conditions, biological spoilage may occur. Oxidative heating rarely occurs. It such cases, it has been associated with low moisture content and/or relatively high fat content.

Color is not an index to quality. Drying procedures and mash bill can both influence degree of darkness.

*Physical Properties*

Corn Distillers Dried Grains with Solubles is light tan to medium brown in color. It is moderately coarse. The normal bushel weight is 33 to 35 pounds. The texture is such that 90% will pass a U.S. No. 6 screen with less than 10% through a U.S. No. 8 screen. It is free flowing and does not cake. Test weight--22-26 lbs./cu.ft.

*Feed Application*

Corn Distillers Dried Grains with Solubles is a source of protein, fat, energy and unknown nutrients. It is widely accepted as an excellent ingredient for dairy feeds and other classes of livestock and poultry.

*Availability*

In general, Corn Distillers Dried Grains with Solubles is available in the Midwest and states east of the Mississippi. Economics determines availability in other areas. It is available year round although production is low in July and August.