



Corn Wet Milled Feed Products



CONTENTS

Member Companies and Plant Locations	2
Foreword	3
The Corn Crop	4
The Corn Kernel	5
The Corn Wet Milling Process	6
Composition of Wet Milled Feed Products	8
Applications of Wet Milled Feed Products	11
Nutrient Values of Wet Milled Feed Products	19
Analytical Examination of Feed Products	24
Literature Cited	25



CONTENTS

TABLES

1. Proximate Analysis of Yellow Dent Corn Grain	5
2. Composition of Corn Wet Milled Feeds	20
3. Nutrient Composition of Corn Wet Milled Feeds	21
4. Mineral Content of Corn Wet Milled Feeds	22
5. Amino Acid Content of Corn Wet Milled Feeds	23

FIGURES

1. The Corn Kernel	5
2. The Corn Wet Milling Process	7



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MEMBER COMPANIES

Archer Daniels Midland Company
P.O. Box 1470
Decatur, Illinois 62525

Cargill, Incorporated
P.O. Box 5662/MS62
Minneapolis, Minnesota 55440-5662

Corn Products International, Inc.
5 Westbrook Corporate Center
Westchester, Illinois 60154

National Starch and Chemical Company
10 Finderne Avenue
Bridgewater, New Jersey 08807-0500

Penford Products Co.
(A company of Penford Corporation)
P.O. Box 428
Cedar Rapids, Iowa 52406-0428

Roquette America, Inc.
1417 Exchange Street
Keokuk, Iowa 52632-6647

Tate & Lyle Ingredients Americas, Inc.
(A subsidiary of Tate & Lyle, PLC)
P.O. Box 151
Decatur, Illinois 62521

PLANT LOCATIONS

Plants:
Cedar Rapids, Iowa 52404
Clinton, Iowa 52732
Columbus, Nebraska 68601
Decatur, Illinois 62525
Marshall, Minnesota 56258-2744

Plants:
Blair, Nebraska 68008-2649
Cedar Rapids, Iowa 52406-2638
Dayton, Ohio 45413-8001
Decatur, Alabama 35601
Eddyville, Iowa 52553-5000
Hammond, Indiana 46320-1094
Memphis, Tennessee 38113-0368
Wahpeton, North Dakota 58075

Plants:
Bedford Park, Illinois 60501-1933
Stockton, California 95206-0129
Winton-Salem, North Carolina 27107

Plants:
Indianapolis, Indiana 46221
North Kansas City, Missouri 64116

Plant:
Cedar Rapids, Iowa 52404-2175

Plant:
Keokuk, Iowa 52632-6647

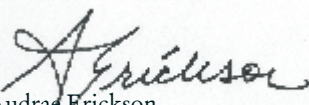
Plants:
Decatur, Illinois 62521
Lafayette, Indiana 47902
Lafayette, Indiana 47905
Loudon, Tennessee 37774

Corn is the basic food plant of modern America and by far its most versatile grain. The end products in which it is found are often far removed from the farmer's field. Corn refining plays a major role in the change from the golden ears of autumn to the beef, chicken, eggs, fish and other foodstuffs that grace our dining room tables.

From the corn refining (wet milling) process comes protein, fiber, minerals and vitamins to feed the cattle, fish, hogs and poultry that enrich our diets. Corn wet milling feed products are an abundant source of protein and energy. About 14 million tons, roughly 25 to 30 percent of the corn used by the corn refining industry goes into feed products.

The remarkable growth of the corn refining industry has made increasing quantities of high quality animal feed ingredients available to U.S. and world markets. Along with this growth has come the need for updated information about the use of corn wet milled feed ingredients in animal rations. Members of the Corn Refiners Association, government agencies, universities and private institutions all contribute to the vast resources of nutritional information necessary to develop the most nutritionally efficient and economically beneficial rations.

The Corn Refiners Association hopes that all those concerned with feed formulation and animal nutrition will find this booklet informative and useful in their day to day work. It describes briefly the process yielding the important ingredients coming from corn refining, reviews their special properties, presents compositional data necessary for using them in ration formulation and discusses use of the products in feeding various classes of animals. While we hope that the information provided is valuable, readers should understand that the feed industry is constantly changing. Researchers are continually discovering new uses for corn derived products, furthering the knowledge of animal feeding requirements and applying their discoveries to the nutritional needs of the world's population.



Audrae Erickson
President
Corn Refiners Association

Readers are advised that the information and suggestions contained herein are general in nature and that specific technical questions should be referred to the Association or member companies. Questions concerning the price and/or availability of products described should be directed to individual Association members.



FOREWORD



THE CORN CROP

Corn (*Zea mays*) is grown in every state: It is truly an American crop. The United States has had an average annual corn production of 10.3 billion bushels for the years 2001 through 2005. To comprehend this amount of corn, imagine that all the corn was loaded onto rail cars linked end to end. A single train loaded with the average corn crop would more than encircle the globe. Another way to envision this quantity of corn is to realize that if the average corn crop was divided equally among all Americans, every man, woman and child would receive over 34 bushels—a bushel equals 56 pounds.

Corn is a very versatile grain that benefits mankind in many ways. Each year, 6 billion bushels of corn are used as feed for cattle, hogs and poultry in the United States. Another 2 billion bushels are exported, which is an integral part of this country's balance of trade.

Approximately 2.9 billion bushels are converted to sweeteners, starch, flour, cereal, liquor, animal feeds, vegetable oils, alcohol for fuel and hundreds of other products.

This portion of the crop is processed by three major industries: corn refiners, who produce starches, sweeteners, ethanol, feed ingredients, corn oil, organic acids, amino acids and polyols; dry millers, who produce flaking grits, snack grits, corn meals and corn flours; and distillers, who produce beverage and industrial alcohol. The largest of these industries, corn refiners, uses approximately 15 percent of annual corn production. Each of these industries also supplies feed ingredients. These corn derived feed ingredients consist primarily of the portions of corn remaining after extraction of primary products such as starch, flour and grits. Different manufacturing processes are used by each of these industries.



Corn kernels have three main parts, the seed coat or pericarp, the starchy endosperm, and the embryo, commonly called the germ (Figure 1).

The pericarp is the outer skin or hull of the kernel which serves to protect the seed. The endosperm, the main energy reserve, makes up about 80 percent of the total weight of the kernel. It is about 90 percent starch and 7 percent gluten (protein), with the remainder consisting of small amounts of oil, minerals and some trace constituents.

ature plant made up of a root like portion and five or six embryonic leaves. In addition, there are present large quantities of high energy oil to feed the tiny plant when it starts to grow, as well as many substances required during germination and early development.

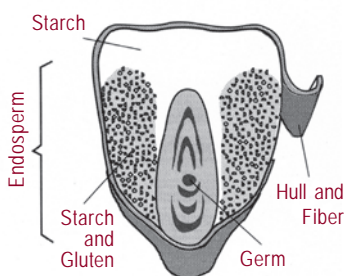


Figure 1.
A Kernel of Corn.

Typical composition of corn grain is shown in Table 1. The embryo contains a min-

Table 1.
Proximate Analysis of
Yellow Dent Corn
Grain

Characteristic	Range	Average
Moisture (% wet basis)	7 – 23	16.0
Starch (% dry basis)	61 – 78	71.7
Protein (% dry basis)	6 – 12	9.5
Fat (% dry basis)	3.1 – 5.7	4.3
Ash (oxide) (% dry basis)	1.1 – 3.9	1.4
Pentosans (as xylose) (% dry basis)	5.8 – 6.6	6.2
Fiber (neutral detergent residue) (% dry basis)	8.3 – 11.9	9.5
Cellulose + Lignin (acid detergent residue) (% dry basis)	3.3 – 4.3	3.3
Sugars, Total (as glucose) (% dry basis)	1.0 – 3.0	2.6
Total Carotenoids (mg/kg)	12 – 36	26.0

Reprinted with permission from White, P.J., and Johnson, L.A., eds., 2003, Corn Chemistry and Technology, American Association of Cereal Chemists, St. Paul, MN.



THE CORN WET MILLING PROCESS

In the corn wet milling process, (Figure 2), the kernel is separated into its component parts, and those parts are then further subdivided and refined.

The wet miller buys shelled corn which is delivered to his plant by truck, barge or rail car. Normally #2 grade corn is purchased, based on U.S. Department of Agriculture standards. The first step in the process is to clean the grain to remove extraneous material such as pieces of cob, foreign seeds, stray metal, fine dirt, or light unwanted material. It then is conveyed to storage silos, holding up to 350,000 bushels, until ready to go to the refinery.

The cleaned corn is transported to large tanks called steeps. Warm water (125°-130°F) containing small quantities of dissolved sulfur dioxide is circulated through the steeps for approximately 40 hours. Soaking softens the kernel and the dilute sulfurous acid formed by interaction of the sulfur dioxide and water ($\text{SO}_2 + \text{H}_2\text{O} = \text{H}_2\text{SO}_3$), controls fermentation and assists in separation of the starch and protein. During steeping, the soluble components are extracted from the intact kernel. At the conclusion of

steeping, the water is drained from the kernels and concentrated in multiple effect evaporators to yield concentrated steepwater. This protein rich extract may be used as a nutrient for microorganisms in the production of enzymes, antibiotics and other fermentation products. The major portion, however, is combined with fiber and gluten in the production of animal feed ingredients.

The softened corn kernels next pass through attrition mills to break them up, loosen the hull and free the germ from the endosperm. Water is added to the attrition mills and a thick slurry of macerated kernels and whole germ results. Because the germ at this stage contains 40-50 percent oil it is lighter than the endosperm and hull. Centrifugal force is used to isolate the germ.

The clean, separated germ is then dried and the crude oil is removed by mechanical presses and/or solvent extraction. The crude oil may be refined to yield a fine quality salad and cooking oil or a raw material for the preparation of corn oil margarines. The extracted germ meal is used in animal feed. Further information on production and use of corn oil

may be found in the booklet *Corn Oil* available from the Corn Refiners Association website, www.corn.org.

The remaining mixture of hull and endosperm then passes through a series of grinding and screening operations. The hull particles are removed on screens, while the finer particles of protein and starch pass through. The hull is used as a constituent in animal feed or for production of refined corn fiber (bran) for food use.

Next, the water slurry of starch and gluten is sepa-

rated in centrifuges. Because starch and gluten differ in density, almost complete separation is obtained. Typical operations yield a gluten stream containing over 60 percent protein, while the starch stream is over 99 percent starch. The gluten is dried and sold as gluten meal (60 percent protein) or it may be used as an ingredient in corn gluten feed (21 percent protein).

The white, nearly pure starch slurry is further washed to remove small quantities of solubles. At this stage the starch slurry

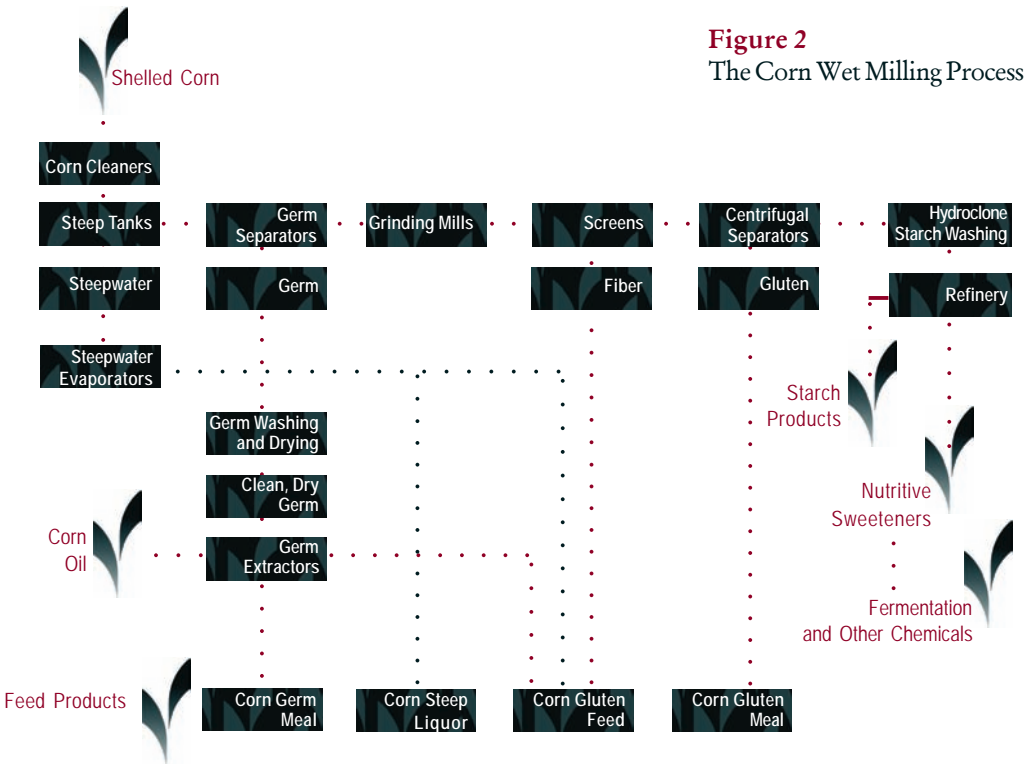


Figure 2
The Corn Wet Milling Process



COMPOSITION OF WET MILLED FEED PRODUCTS

may be diverted to make sweeteners or further processed to make any common (unmodified) corn starch. Various modified or derivatized starches may be produced by treating the slurry of washed starch with chemicals or enzymes. After treatment, the products are recovered by filtration or centrifugation and the starch is dried. Information on the starch and sweetener products of the corn wet milling industry may be found in the booklets *Corn Starch* and *Nutritive Sweeteners from Corn* available from the Corn Refiners Association website, www.corn.org.

The four major feed products derived from corn wet milling are described as follows by the Corn Refiners Association:

Corn gluten feed is that part of commercial shelled corn and process residuals that remain 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 and corn starch derivatives. It may or may not be pelletized, and may or may not contain corn steep liquor and/or corn germ meal. It may con-

tain up to 0.5 percent by weight of a nutritive or non-nutritive, inert, non-toxic conditioning agent to improve flowability. It may not contain other products that are blended or admixed after its initial manufacture, or after pelleting.

Corn gluten feed is a medium protein, medium energy ingredient. It is widely used in complete feeds or concentrate for dairy and beef cattle, poultry (layer and turkey breeders), swine, and as a carrier for added micronutrients. It is commonly provided at around 20 percent protein at 10 percent moisture.

A number of facilities also offer wet corn gluten feed. Wet corn gluten feed is made by screening and pressing wet corn fiber to reduce the water content. It can be sold as is, or combined with steep liquor, corn germ meal or fermentation residues to produce a product with approximately 40 to 60 percent dry matter. Wet corn gluten feed is commonly used in diets for feedlot cattle and dairy cattle.

Corn gluten feed is a major product in international trade in feed ingredients and large volumes of U.S. corn gluten feed are exported to

the European Union. A bilateral agreement between the U.S. and the EU provides additional requirements for corn gluten feed exported to the European Union that are contained in the European Union Harmonized Tariff Schedules. That definition states that the applicable tariff number for corn gluten feed "includes only residues from the manufacture of starch from maize, and does not cover blends of such residues with products derived from other plants or products derived from maize otherwise than in the course of the production of starch by the wet process, containing: screenings from maize used in the wet process in a proportion not exceeding 15 percent by weight, and/or; residues of maize steep-water, from the wet process, including residues of steep-water used for the manufacture of alcohol or other starch derived products;

These products may also contain residues from the extraction of maize germ oil by the wet milling process." European Union customs* regulations also specify limits for starch, fat and protein content for imported corn gluten feed. The Corn Refiners Association makes available a program for U.S. producers to certify that their exports meet these definitions and analytical requirements. This certificate, along with a certificate of analysis from the USDA Federal Grain Inspection Service, is required by the EU as a condition of normal customs treatment.

Corn gluten meal is a high protein, high energy ingredient consisting of protein (gluten) separated in the corn wet milling process in combination with minimal quantities of starch and fibrous fraction not recovered in the primary separation.

* The combined customs nomenclature of the EU places corn gluten feed in tariff classification 2309.90.20 with the following additional requirements: "Their starch content may not exceed 28% by weight on the dry product in accordance with the method contained in Annex I(1) to Commission Directive 72/199/EEC, their fat content may not exceed 4.5% by weight on the dry product determined in accordance with method A contained in Annex I to Commission Directive 84/4/EEC and their protein content may not exceed 40% on the dry product determined in accordance with the method contained in Annex I(2) to Commission Directive 72/199/EEC." (See http://ec.europa.eu/taxation_customs/customs/customs_duties/tariff_aspects/combined_nomenclature/index_en.htm)

This high energy protein concentrate is commonly provided at 60 percent protein. Corn gluten meal is a valuable source of methionine to complement other commonly used protein sources. The high xanthophyll content of corn gluten meal makes this product particularly valuable as an efficient pigmenting ingredient in poultry feeds. Corn gluten meal is also an excellent feed ingredient for cattle, providing a high level of rumen-protected protein.

Corn germ meal is a medium protein, medium energy ingredient obtained from the corn germ fraction after the corn oil has been removed.

Since germ represents only a small portion of the kernel, only a limited quantity of corn germ meal is available. It is generally used as an ingredient in corn gluten feed. It is useful as a carrier for liquid nutrients and is commonly provided at 20 percent protein.

Corn steep liquor (also known as condensed fer-

mented corn extractives) is, on a dry matter basis, a high protein, high energy liquid ingredient consisting of the soluble portions of the corn kernel removed by the steeping process and concentrated to high solids.

Corn steep liquor is sometimes combined with other ingredients in corn gluten feed or may be sold separately as a liquid protein source for beef and dairy feeding, or as a nutritional pellet binder. It is a valuable source of B-vitamins, minerals and unidentified growth factors.

Amino acids produced by corn wet millers through fermentation of dextrose provide a vital link in animal nutrition systems. Most grain feeds do not have the amount of lysine required by swine and poultry for optimal nutrition. Economical corn based lysine is now available worldwide to help supplement animal feeds. Threonine and tryptophan for feed supplements produced from corn are also available.

Optimum nutrition of each class of livestock and poultry is of primary concern to the feed manufacturer. Each of the corn wet milled feed products contributes different nutritional characteristics to the finished feed in which they are used. In general, the four major ingredients supplied by refiners are classified as “protein supplements” according to the National Research Council. In addition to the range of total protein content, the four feedstuffs each have different levels of various essential amino acids, vitamins and minerals.

With numerous ingredients to choose from, feed formulators generally use computer solutions for feed compounding questions. Information is entered concerning the nutritional characteristics of each available ingredient, its price and availability. Then the nutritional needs of the animal being fed are entered. The computer program recommends a complete feed for the animal, meeting all its nutritional requirements from available ingredients. With the use of computer modeling to predict nutrient requirements, nutrient management is improved through less overfeeding, increased efficiency of nutrient utilization, maximized performance and enhanced economic benefit.

While much of today’s feed formulation involves economic considerations, specific properties of several wet milled feed products, aside from price, contribute much to their usage.

Beef Cattle

Ruminants, such as beef and dairy cattle and sheep, are unique as food producers in that they can combine carbon skeletons, obtained from fermentation of cellulosic feedstuffs, and nitrogen from other sources to produce meat, milk and wool. However, to maximize efficiency of production, high producing dairy cows and rapidly growing calves require supplemental protein which escapes ruminal degradation and is digested and absorbed in the small intestine.

Corn gluten meal was found to be an effective protein source for beef cattle as early as 1933¹. Corn gluten meal plus urea was equal to soybean meal in supporting growth of calves and lambs². Corn gluten meal was an effective substitute for soybean meal when alternating day protein supplementation of cattle grazing corn-stalks³. Corn gluten meal is



APPLICATIONS OF WET MILLED FEED PRODUCTS

an excellent source of slowly degraded protein^{4,6} with approximately 60 percent of the protein escaping the rumen^{7,8} and passing into the small intestine where it is readily absorbed⁹. For example, the quantity of lysine absorbed from the small intestine was similar when an equal amount of corn gluten meal and soybean meal protein was fed. The high rumen escape of lysine in corn gluten meal relative to soybean meal, and high bioavailability of the corn gluten meal protein, made this possible.

The potential for corn gluten meal to improve efficiency of protein utilization has been demonstrated in the growing calf⁶ and high producing dairy cow^{10,11}. Corn gluten meal in combination with other nitrogen sources offers the opportunity to formulate supplements which are nutritionally equal to many natural protein supplements, but with a considerable cost savings. Corn germ meal has been shown to be an excellent source of supplemental fat in beef finishing diets¹².

Corn steep liquor has been demonstrated to be a useful ingredient in beef cattle feeding. Up to 15 percent was successfully fed in concen-

trate mixtures for growing crossbred calves¹³. Adding 5 percent steep liquor concentrate to corn forage at ensiling significantly increased digestibility of dry matter, crude protein, crude fiber and nitrogen-free extract (NFE) with growing cattle¹⁴. Corn steep liquor was an effective protein source for wintering dry, pregnant cows on native range^{15,16}.

Dry corn gluten feed pellets are an excellent source of protein, energy and minerals in beef cattle diets. Corn gluten feed, either as dry, wet or ensiled, could be substituted for up to 50 percent of the dry matter in high-concentrate diets for cattle and sheep, comparing favorably with corn + urea or corn + soybean meal diets¹⁷. High dietary levels (up to 80 percent of the diet) supported cattle gains that were nearly equal to those of cattle fed corn silage¹⁸. Growing steers fed corn silage-based diets supplemented with dry corn gluten feed pellets grew faster and required less feed per unit of gain than did those fed a similar diet supplemented with soybean meal¹⁹. The very low acid detergent insoluble nitrogen values of corn gluten feed suggest that the crude protein is nearly

100 percent available²⁰. In diets for growing-finishing cattle, corn gluten feed pellets were found to have 86-90 percent of the energy of corn^{21, 22}. When supplementing high-forage growing diets, the corn gluten feed was found to be equal to corn in energy due to the complementary effects on ruminal fiber digestion^{18, 23, 24}. This complementary effect occurs because the fiber-digesting microbial population in the rumen is maintained with corn gluten feed; whereas a shift towards a starch digesting microbial population occurs when high-starch cereal grains are fed. This is especially important when supplementing beef cows fed hay-based diets^{25, 26}. The high phosphorus content of corn gluten feed is also an asset in phosphorus deficient high-forage diets. Corn gluten feed is an effective supplement for beef cattle grazing native range²⁷⁻²⁹ or fed native grass or prairie hay^{26, 30}.

Wet corn gluten feed is made by screening and pressing wet corn fiber to reduce the water content so that when combined with steep liquor, the final product contains approximately 40 percent dry matter. Wet corn gluten feed is very palatable and tends to increase dry matter intake when

added to feedlot diets. Because of its high digestibility, wet corn gluten feed is an excellent source of protein, energy and roughage in medium to high energy diets for feedlot cattle¹⁷. Wet corn gluten feed has an energy value as high as 95 percent of corn on an equal dry matter basis when fed in typical feedlot diets. This value may be even higher if part of the roughage is replaced with wet gluten feed or if the diets are fed at restricted intake. The need for additional roughage is greatly reduced or eliminated when 50 to 70 percent wet corn gluten feed is fed in a finishing diet²².

Dairy Cattle

Dairy cattle also benefit from the excellent feeding value of corn gluten feed. Dry corn gluten feed can increase feed intake and milk production when added to typical corn-corn silage lactation diets. Diets containing as much as 60 percent dry corn gluten feed have been fed successfully to lactating cattle³¹. Changing rations of lactating cows to include 20 percent dry corn gluten feed and 20 percent concentrate in place of 40 percent concentrate did not affect feed intake, milk yield, milk composition, body condition or levels of metabolites or minerals in

blood serum³². Up to 27 percent of dietary dry matter was successfully included without loss of milk yield, percentage of milk protein and non-fat solids³³. A combination of 20 percent corn gluten feed and 1 percent sodium bicarbonate was an effective replacement for neutral detergent fiber (NDF) from corn silage²². Dried corn gluten feed was found to be a satisfactory source of energy, protein and fiber when it comprised 15 to 20 percent of feed dry matter³⁴.

Wet corn gluten feed is also an excellent source of protein, energy and digestible fiber for lactating dairy cows. Fat-corrected milk production was maintained when wet corn gluten feed replaced corn and soybean meal at 25-30 percent of the diet dry matter in corn-corn silage based diets^{35, 36}. Milk-fat percentage increased linearly as dietary level of wet corn gluten feed increased from approximately 20 to 40 percent^{36, 37}. Research suggests that wet gluten feed can replace at least 33 percent of the neutral detergent fiber in forage-based diets for dairy cattle without changing the acetate:propionate ratio³⁸, which is necessary for maintaining high milk fat levels.

When wet corn gluten feed was fed as 90 percent of the diet to dairy replacement heifers, daily gain and feed efficiency were significantly improved compared with heifers fed alfalfa haylage, oatlage or sorghum-soybean silage based diets³⁹.

Corn steep liquor has become an important source of protein, energy and phosphorus in liquid feed supplements for beef and dairy cattle. Corn steep liquor is equal to soybean meal and equal or superior to urea as a crude protein source in feedlot diets^{40, 41}. A liquid supplement containing 71 percent corn steep liquor was equal to cottonseed meal as a supplemental protein source for cows grazing dormant native range. Supplement blocks are often used to provide nutrients for range cattle. Corn steep liquor serves as both a nutrient source and binder in many range block formulations. A pelleted combination of raw soybean hulls and condensed corn steep liquor successfully replaced a portion of the forage, grain and soybean meal in diets for lactating dairy cows without decreasing lactational performance⁴². Corn steep liquor was fed at 10 percent levels in concentrate mixtures without affecting the produc-

tion and efficiency of lactating cows with an economic advantage⁴³.

Sheep

The nutritive value of corn gluten meal for sheep has been known for many years^{44,45}. Dry and wet corn gluten feed are excellent sources of nutrients for growing lambs^{22,46}. Lambs fed diets containing 50 percent dry corn gluten feed pellets grew as fast as lambs fed corn based diets supplemented with sunflower or soybean meal¹⁹. Dietary corn gluten feed levels above 50 percent of the diet are not recommended in order to avoid copper toxicity¹⁹.

When finishing lambs were fed diets containing 25 or 50 percent dry corn gluten feed, which was substituted on an equal dry matter basis for corn silage, rate of gain and feed efficiency were improved⁴⁷. On an equal-protein basis, dry corn gluten feed was equal to corn plus soybean meal for finishing lambs¹⁷. Corn gluten meal can be used to partially replace corn and soybean meal in diets for lambs⁴⁸, feedlot sheep⁴⁹ and lactating ewes⁵⁰.

Poultry

Nutritional requirements of poultry vary greatly, depending on type of bird and stage of production. Recognition

of the value of corn gluten meal was noted in 1935 in turkey diets⁵¹ and in 1939 in diets for chicks and laying hens⁵². Corn gluten meal is used frequently in broiler diets due to its unique nutritional qualities. Because of its high protein (60 percent) and energy content, it is ideally suited for the nutrient-dense high-efficiency diets sought by the broiler industry. Feeding trials have demonstrated that corn gluten meal can replace animal protein in diets for broilers⁵³⁻⁵⁵. Corn gluten meal is high in xanthophylls, the carotenoid pigments which give egg yolks and poultry their golden yellow pigmentation⁵⁶. The xanthophyll from corn gluten meal has been shown to have high value in pigmenting broiler skin⁵⁷ and the yolks of eggs⁵⁸. Energy content of corn gluten meal is second only to that of pure fats and oils among available ingredients. The high linoleic acid content is also important in helping to meet the relatively large essential fatty acid requirements of chickens⁵⁹. Corn gluten meal is also high in methionine, an essential amino acid deficient in many feed ingredients. The methionine in corn gluten meal is highly digestible by chicks⁶⁰, being approximately 98.9 percent digestible. The lysine and

metabolizable energy (ME) of corn gluten meal is also highly digestible⁶¹.

Corn gluten feed can be substituted for 15 percent of the corn and soybean meal in balanced diets of laying hens, without decreasing feed efficiency or egg production^{62, 63}. Some studies have demonstrated that as high as 20 percent corn gluten feed could be included in layer diets without a negative impact on economic production⁶⁴. Recent research shows that the metabolizable energy value of corn gluten feed for broilers can be as high as 2.8 to 3.1 Kcal/g, which is much greater than the 1.8 Kcal/g in the 1994 NRC requirements for poultry^{56, 65}.

With the rapid expansion of the turkey industry, there is considerable opportunity to make efficient utilization of corn gluten feed in turkey production. Turkey poults can effectively utilize 10-20 percent corn gluten feed when diets are balanced to be isocaloric and isonitrogenous to typical corn-soy basal diets⁶⁶.

Corn germ meal is an excellent source of amino acids for poultry due to the desirable balance of essential amino acids and its high

energy content. Up to 22 percent corn germ meal could be successfully used in broiler diets⁶⁷ while the inclusion of up to 50 percent corn germ meal in layer diets did not affect the performance, internal egg quality or egg shell quality⁶⁸.

Dried corn steep liquor concentrate is a useful product in diets for broilers⁶⁹⁻⁷², laying hens⁷³ and turkeys⁷³. Inclusion of corn steep liquor concentrate in layer diets results in an improvement in internal albumen quality as indicated by increased Haugh units^{73, 74} that may be economically beneficial in older hens where interior egg quality typically declines.

Swine

The first trial evaluating corn wet milled feed products for swine was conducted in 1920⁷⁵. Since that time, our understanding of the pig's nutrient requirements and the ability of corn wet milled feed products to meet these requirements has become much more sophisticated. Corn germ meal has been shown to be equal to soybean meal as a protein source for the growing pig⁷⁶. Defatted corn germ meal has been demonstrated to be effective in diets for growing and finishing pigs at levels of

15 to 40 percent of the diet⁷⁷⁻⁷⁹.

Pelleted corn gluten feed can replace up to 30 percent of the corn in a corn-soybean meal diet for the finishing pig without reducing performance⁸⁰⁻⁸⁴. If supplemental lysine and tryptophan are added, corn gluten feed can replace both corn and soybean meal at levels up to 30 percent of the diet. Pelleting corn gluten feed improves nitrogen retention by increasing tryptophan and/or energy availability. Corn gluten feed contains approximately 80 percent of the energy of corn for the growing pig⁸⁵. Corn gluten feed has an ME value of 2.77 Kcal/g of dry matter⁸⁶. For gestating sows, it contains 70 percent of the energy of corn, which makes it an excellent source of nutrients because feed intake and weight gain are deliberately restricted⁸⁷. Gestating diets containing as much as 50 percent corn gluten feed have allowed adequate feed intake and weight gain⁸⁸.

Corn steep liquor with germ meal and bran has been used as a supplemental protein source in corn and sorghum grain based diets for pigs, with a nitrogen-corrected ME of 3.79 Kcal/g dry matter⁸⁹. This product can provide up to 30 percent of the total dietary lysine without depressing performance of the growing pig⁹⁰.

Pets

Corn wet milled feed products are desirable nutrient sources for the pet food industry. Pet food manufacturers use corn wet milled feeds to provide optimum nutrient density for each physiological stage of life.

Corn gluten meal is a common ingredient in many pet foods⁹¹⁻⁹³. Because it is 60 percent protein and high in metabolizable energy, corn gluten meal provides much nutrition in a nutrient-dense package. This allows manufacturers greater flexibility in adding other products with lower nutrient densities to improve diet acceptability, appearance, handling properties and shelf life.

The available cystine content in corn gluten meal enhances the palatability of dry, extruded cat foods. The linoleic acid and methionine content of corn gluten meal aids in coat condition for all companion animals⁹⁴. Corn gluten meal was found to be comparable to fish meal in nutritive value and urine acidifying effect in diets for cats⁹⁵.

Obesity is a factor contributing to the reduced life

span of many pets. Diets designed to provide optimum nutrition for each physiological stage of life will help alleviate this problem. Several lines of low-calorie pet foods are available that enable the pet to receive all essential nutrients, without excessive calories. Corn gluten feed has been a major ingredient in these foods because of its medium protein and energy content. Corn gluten feed, containing 6 to 10 percent crude fiber, is a good source of fiber and a valuable aid in controlling obesity in adult dogs.

Rabbits

Rabbit production is important in many parts of the world. Corn gluten meal has been reported to be a nutritive feed ingredient in the diet of growing rabbits in several studies⁹⁶⁻⁹⁸.

Fish

Aquaculture has become a big business in the United States and around the world as consumers search for new and economical sources of food protein. Because of this increase, fish nutritionists have intensified their search for the most efficient and economical feed sources for catfish, rainbow trout, tilapia and other commercial breeds. Corn gluten meal, with its 60 percent protein

content, is well suited as a protein source for fish. Although corn gluten meal may be limiting in certain amino acids required for fish, these may be included through use of various amino acid supplements or other feedstuffs while maintaining the economic advantages for the entire formulation.

Research has shown that corn gluten meal and corn gluten feed can be efficient and cost-effective replacements for fish meal. Tilapia fed balanced diets containing 16 percent corn gluten meal or corn gluten feed performed as well as fish consuming diets containing fish meal⁹⁴. In a 75-day feeding study, diets containing corn gluten meal with 32 or 36 percent crude protein yielded higher weight gain, higher protein efficiency ration, and better or equal feed conversion ratio values of tilapia than a commercial fish feed containing 36 percent protein and fish meal⁹⁹. The intensities of flavor characteristics of cooked filets of tilapia raised on pellets containing 23 and 34 percent corn gluten meal were not significantly different from fish fed commercial feed without corn gluten meal¹⁰⁰. Diets with up to 50 percent corn gluten feed have been successfully used

in diets for pond-raised catfish¹⁰¹. Protein from corn gluten meal was able to replace one third of the fish meal protein in diets for turbot¹⁰² and up to 60 percent of the fish meal protein in diets for gilthead sea bream juveniles with no negative effects on fish performance¹⁰³. Corn gluten meal could replace up to 40 percent of fish meal protein in diets for Japanese flounder¹⁰⁴ and 23 percent of fish meal protein in diets for the Australian short-finned eel¹⁰⁵.

Corn gluten meal is also an important source of carotenoid pigments (xanthophylls) that contribute to desirable pigmentation in farm-raised fish. Gluten meal is a natural source of these pigments in contrast to several other pigmentation additives that are produced through chemical processes.

As users of feed ingredients from the corn refining industry know, many considerations go into their decisions to use a particular ingredient. Corn refiners are, of course, only one among many reliable ingredient suppliers for the feed industry. Each contributes ingredients which meet individual requirements of the manufacturer.

As the corn refining business

has expanded, more of its products have been available to feed manufacturers. Corn refiners today ship over 11 million tons of feed products annually. In today's business atmosphere, where feed manufacturers need every bit of flexibility possible, corn refiners offer valuable products to meet their needs.

Data in Table 2 show the typical nutrient concentrations in the four major corn wet milled feedstuffs. Major considerations for animal feed formulators such as energy density for different species are shown in Table 3. Table 4 contains the typical mineral content of feedstuffs from corn wet milling and Table 5 shows typical vitamin and amino acid contents of the feeds. The tables include data on "dry matter", a common term in the feed industry, which equals 100 — the percent moisture as determined by an appropriate analytical method.

Data contained in Tables 2-5 are "typical" values and do not represent guaranteed compositions. Such factors as changes in corn composition, geographical distribution, processing and storage conditions can influence



NUTRIENT VALUES OF WET MILLED FEED PRODUCTS

feedstuff composition. Consequently, users of these tables are cautioned that individual product samples may vary from the values cited in these tables. Because composition of wet corn gluten feed varies depending on the manufacturing location readers are advised to obtain composition data for this product from their supplier.

Energy

Metabolizable energy intake below the requirement is the most common cause of sub-optimum performance by livestock and poultry. Corn gluten meal has a very high level of metabolizable energy for all classes of livestock and poultry. Ruminants, such as cattle and

sheep, metabolize the greatest amount of energy from corn gluten feed because of their ability to effectively utilize the fiber components. This is the reason cattle derive almost as much energy from gluten feed as from corn gluten meal. Research has shown that the net energy gain of wet corn gluten feed is 0.6 mcals/lb¹⁰⁶.

Corn gluten feed and corn germ meal are similar to wheat millfeeds and other high-fiber grain co-products in metabolizable energy content for poultry and swine. Often overlooked, corn steep liquor is an excellent source of energy for livestock and poultry when expressed on a dry matter basis.

Table 2.
Composition of Corn Wet Milled Feeds

	Unit	Corn Gluten Feed	Corn Gluten Meal	Corn Germ Meal	Corn Steep Liquor
Dry Matter	%	87-90	90	90	50
Protein	%	18-22	60	20.5	23
Fat	%	2-5	2.5	1	0
Fiber	%	6-10	2.5	12	0
Acid Detergent Fiber (ADF)	%	13	5	14	0
Neutral Detergent Fiber (NDF)	%	35	—	—	0
Ash	%	6.5-7.5	1.8	3.8	8
<i>Additional Data</i>					
Density	lb/cu. ft.	25-30	33-36	24-28	10.5
Xanthophylls	mg/lb	16	225	0	0
Linoleic Acid	%	2.2	3.2	.5	0
— Data Not Available					

Fiber

Structural carbohydrates in corn wet milled feeds are high in hemicellulose, moderate to low in cellulose and low in lignin. Steeping corn in dilute acid increases the susceptibility of hemicellulose to microbial attack. Corn cellulose swells during the steeping process and is also quite vulnerable to cellulolytic bacteria, especially when fed in the wet form as with wet corn gluten feed. The primary fiber component measured by the crude fiber assay is cellulose. Consequently, these data show (Table 2) that cellulose is very low in gluten meal and absent from corn steep liquor.

Fats

Fats are the most concentrated form of metabolizable energy available to the feed industry. Corn steep liquor

is the only wet milled feedstuff that does not contain an appreciable amount of fat (Table 2). The unsaturated nature of these fats may enhance utilization of saturated fats in other feedstuffs by poultry⁵⁹. In ruminants, unsaturated fatty acids are hydrogenated by ruminal microflora. This tends to increase the metabolizable energy available to ruminants by removing hydrogen from the rumen, resulting in less methane production. The essential fatty acids, linoleic, linolenic and arachidonic are required in all diets. Corn wet milled feeds, with the exception of corn steep liquor, contain corn oil which is high in linoleic acid. This is especially important to poultry, which have a high requirement for linoleic acid.

Table 3.
Nutrient Composition of Corn Wet Milled Feeds

	Unit	Corn Gluten Feed	Corn Gluten Meal	Corn Germ Meal	Corn Steep Liquor
Dry Matter	%	90	90	90	50
Ruminants					
TDN	%	80	75	67	40
Net Energy					
Gain	mcal/lb	.60	.60	.44	-
Maintenance	mcal/lb	.80	.85	.70	-
Lactation	mcal/lb	.77	.80	.69	-
Metabolizable Energy					
Swine	kcal/lb	1130	1600	1360	920
Chicks	kcal/lb	830	1760	770	725
Hens	kcal/lb	830	1760	770	725
Turkeys	kcal/lb	830	1760	770	725

Amino Acids

The amino acid requirements of swine and poultry have been well defined. Amino acid concentrations of corn wet milled feeds are expressed as a percentage of the feed in Table 5. Corn germ meal contains the highest quality protein of the four feedstuffs, as it is nearly adequate in lysine, methionine and tryptophan. Corn gluten meal is high in methionine and essential amino acids. This is very useful to the feed manufacturer in that it allows utilization of low-protein feedstuffs in combination with corn gluten meal to formulate a nutritionally balanced diet at the lowest cost. Corn gluten feed can serve as a useful amino acid source in swine and poultry diets when synthetic amino acids or natural protein sources are added that

complement its amino acid profile.

Dietary amino acid requirements of ruminants are less well defined than are those of swine or poultry because the microbial population in the rumen converts both feed protein and non-protein nitrogen to microbial protein. Optimum protein utilization occurs in the ruminant when just enough dietary protein is degraded in the rumen to support maximum microbial protein synthesis with the remainder being digested in the small intestine. Corn gluten meal is ideal for ruminants because 60 to 70 percent of the protein escapes ruminal digestion and is available in the small intestine. Corn gluten meal is also high in methionine which is often times the first-limiting amino acid in microbial pro-

Table 4.
Mineral Content of Corn Wet Milled Feeds

	Unit	Corn Gluten Feed	Corn Gluten Meal	Corn Germ Meal	Corn Steep Liquor
Dry Matter	%	90	90	90	50
Calcium	%	0.05	.07	.04	.14
Phosphorus	%	1.00	.48	.30	1.80
Potassium	%	1.50	.20	.34	2.40
Magnesium	%	0.50	.08	.30	0.70
Sulfur	%	0.30	.65	.30	0.60
Sodium	%	0.15	.06	.07	0.11
Iron	ppm	363	282	337	110
Zinc	ppm	250	31	92	70
Manganese	ppm	58	7	4	29
Copper	ppm	13	24	4	15

tein. Consequently, feeding corn gluten meal to high producing ruminants increases the amount and quality of amino acids available for absorption^{107, 108}.

Minerals

Minerals are essential to all animals in that they give structural integrity to bones and teeth, help regulate body pH and osmolarity and act as cofactors for a multitude of enzymes. Corn wet milled feedstuffs are high in phosphorus (Table 4), which is the most costly mineral routinely added to livestock and poultry diets. These feedstuffs are also excellent sources of potassium, magnesium and sulfur. Sulfur is

especially beneficial in diets for ruminants containing large amounts of non-protein nitrogen. Wet milled feedstuffs are also a good source of trace minerals, particularly iron and zinc. These feedstuffs are low in calcium and sodium, which are relatively inexpensive to add to most diets.

Vitamins

Vitamins are essential to animals in that they are required for metabolism of other dietary nutrients. Corn wet milled feeds are good sources of most of the B-vitamins and choline (Table 5). Corn gluten meal is a good source of carotenoids, which have vitamin A activity.

Table 5.
Amino Acid Content of Corn Wet Milled Feeds

	Unit	Corn Gluten Feed	Corn Gluten Meal	Corn Germ Meal	Corn Steep Liquor
Dry Matter	%	90	90	90	50
<i>Vitamins</i>					
Choline	mg/lb	688	160	738	1550
Niacin	mg/lb	32	27	13	38
Riboflavin	mg/lb	.9	.9	1.8	2.7
Thiamin	mg/lb	.9	.1	2	1.3
Biotin	mg/lb	.15	.08	.1	.15
Carotene	mg/lb	3	7.27	.9	0
<i>Amino Acids</i>					
Arginine	%	.78	2.08	1.30	1.00
Histidine	%	.61	1.40	0.69	.70
Isoleucine	%	.88	2.54	.69	.70
Leucine	%	2.20	10.23	1.79	2.0
Lysine	%	.64	1.01	.90	.80
Methionine	%	.37	1.78	.58	.50
Threonine	%	.78	2.20	1.09	.90
Tryptophane	%	.15	.30	.20	.05



ANALYTICAL EXAMINATION OF FEED PRODUCTS

Members of the Corn Refiners Association maintain the highest quality control standards on their products.

However, some variation in nutrient content of feedstuffs produced at various plants is inevitable. When formulating diets for economic advantages, knowing the exact nutrient concentration is of critical importance.

Through its Technical Affairs Committee, the Corn Refiners Association has developed a number of analytical methods applicable to examination of corn wet milled feedstuffs. These methods are published in *Analytical Methods of the Member Companies*, available

from the Association's website, www.corn.org.

In addition to those methods developed by the Corn Refiners Association, the Association of Official Analytical Chemists has developed analytical methods for some properties not included in the Corn Refiners Association methods (such as neutral and acid detergent fiber, amino acids, acid detergent lignin) which may be used in the examination of feedstuffs. Together, these methods provide detailed procedures to accurately determine the concentration of nutrients and other important properties of wet milled feed products.

LITERATURE CITED

1. Weber AD. The relative value of cottonseed meal, linseed meal, and corn gluten meal in fattening cattle rations. *Proc Amer Soc Anim Prod.* 1933;70:72.
2. Umunna NN, Klopfenstein TJ, Hasimoglu S, Woods WR. Evaluation of corn gluten meal with urea as a source of supplementary nitrogen for growing calves and lambs. *Anim Feed Sci Tech.* 1982;7:375-85.
3. Collins RM, Pritchard RH. Alternative day supplementation of corn stalk diets with soybean meal or corn gluten meal fed to ruminants. *J Anim Sci.* 1992;70:3899-908.
4. Annexstad RJ, Stern MD, Otterby DE, Linn JG, Hansen WP. Extruded soybean and corn gluten meal as supplemental protein sources for lactating dairy cattle. *J Dairy Sci.* 1987;70:814-22.
5. Loerch SC, Berger LL, Gianola D, Fahey Jr. GC. Effect of dietary protein source and energy level on in situ nitrogen disappearance of various protein sources. *J Anim Sci.* 1983;56:206-16.
6. Rock DW, Klopfenstein TJ, Ward JK, Britton RA, McDonnell ML. Evaluation of slowly degraded proteins: Dehydrated alfalfa and corn gluten meal. *J Anim Sci.* 1983;56:476-82.
7. Stern MD, Rode LM, Prange RW, Stauffacher RH, Satter LD. Ruminant protein degradation of corn gluten meal in lactating dairy cattle fitted with duodenal T-type cannulae. *J Anim Sci.* 1983;56:194-205.
8. Zinn RA, Bull LS, Hemken RS. Degradation of supplemental proteins in the rumen. *J Anim Sci.* 1981;52:857-66.
9. Stern MD, Satter LD. In vivo estimation of protein degradability in the rumen. In: Owen FN, editor. *Protein Requirements for Cattle Symposium.* Stillwater OK: Oklahoma State University Press; 1982. p. 57-71.
10. Forster RJ, Grieve DG, Buchanan-Smith JG, Macleod GK. Effect of dietary protein degradability on cows in early lactation. *J Dairy Sci.* 1983;66:1653-62.
11. Gracia MD, Own FG, Lowry SR. Corn gluten meal and dried blood meal mixture for dairy cows in midlactation. *J Dairy Sci.* 1989;72:3064-9.
12. Montgomery SP, Drouillard JS, Sindt JJ, Greenquist MA, Depenbusch BE, Good EJ, Loe ER, Sulpizio MJ, Kessen TJ, Ethington RT. Effects of dried full-fat corn germ and vitamin E on growth performance and carcass characteristics of finishing cattle. *J Anim Sci.* 2005;83:2440-7.
13. Gupta RS, Desai MC, Talpada PM, Shukla PC. Effect of corn steep liquor feeding on growth of cross-bred calves. *Indian J An Nutr.* 1990;7:279-82.
14. McCullough ME. Effect of formic acid and dried steep liquor concentrate on digestibility and steer growth from corn silage. *J Anim Sci.* 34;127:131.
15. Lusby KS, Armbruster SL, Dvorak MJ. Condensed molasses solubles and corn steep liquor as protein supplements for range cows. 1982. Report No.: An. Sci. Res. Rep. Okla. Agr. Exp. Sta. MP-112.

16. Wagner JJ, Lusby KS, Horn GW, Dvorak MJ. Corn steep liquor and fermented ammoniated condensed whey as protein sources for lactating cows and yearling heifers grazing winter native range. 1982. Report No.: An. Sci. Res. Rep. Okla. Agr. Exp. Sta. MP-112.
17. Bowman JGP, Paterson JA. Evaluation of corn gluten feed in high-energy diets for sheep and cattle. *J Anim Sci.* 1988;66:2057-70.
18. Kampman KA, Loerch SC. Effects of dry corn gluten feed on feedlot cattle performance and fibre digestibility. *J Anim Sci.* 1989;67:501-12.
19. Morrill D. Corn gluten feed for sheep. In: *Corn Gluten Feed for the Livestock Industry.* AS-565. Iowa State University, Ames.; 1985. p. 35-7.
20. Firkins JL, Berger LL, Fahey Jr. GC, Merchen NR. Ruminant nitrogen degradability and escape of wet and dry distillers grains and wet and dry corn gluten feed. *J Dairy Sci.* 1986;67:1936-43.
21. DiCostanzo A, Chester-Jones H, Plegge SD, Peters TM, Meiske JC. Energy value of dry maize gluten feed in starter, growing, or finishing steer diets. *Anim Prod.* 1990;51:75-84.
22. Firkins JL, Berger LL, Fahey Jr. GC. Evaluation of wet and dry distillers grains and wet and dry corn gluten feed for ruminants. *J Anim Sci.* 1985;60:847-60.
23. Barclay RA, Faulkner DB, Berger LL, Cmarik GC. Feedlot performance of steers fed corn bran and soyhulls. *J Anim Sci.* 1983;61(Suppl 1):130.
24. Hannah SM, Paterson JA, Williams JE, Kerley MS. Effects of corn vs corn gluten feed on site, extent and ruminal rate of forage digestion and on rate and efficiency of gain. *J Anim Sci.* 1990;2536:2545.
25. Cordes CS, Turner KE, Paterson JA, Bowman JGP, Forwood JR. Corn gluten feed supplementation of grass hay diets for beef cows and yearling heifers. *J Anim Sci.* 1988;66:522-31.
26. Fleck AT, Lusby KS, Owens FN, McCollum FT. Effects of corn gluten feed on forage intake, digestibility and ruminal parameters of cattle fed native grass hay. *J Anim Sci.* 1988;66:750-7.
27. Fleck AT, Lusby KS. Corn gluten feed or soybean meal as winter supplements for pregnant beef cows grazing native range. 1986. Report No.: Animal Science Research Report, Oklahoma Ag. Exp. Sta. MF-2488.
28. Fleck AT, Lusby KS, McCollum FT. The value of corn gluten feed as a supplement for beef cattle grazing native range. 1987. Report No.: Anim. Sci. Res. Rep. Okla. Agr. Exp. Sta. Bull MP-119.
29. Fleck AT, Lusby KS, McCollum FT. Corn gluten feed or soybean meal as summer supplements for growing beef cattle grazing native range. 1986. Report No.: Anim. Sci. Res. Rep. Okla. Agr. Exp. Sta. MP-118.
30. Younis RA, Wagner DG. Effect of corn gluten feed, soybean meal, and cottonseed meal on intake and utilization of prairie hay by beef heifers. 1990. Report No.: Anim. Sci. Res. Rep. Okla. Agr. Exp. Sta. MP-129.

31. Fellner V, Belyea RL. Maximizing gluten feed in corn silage diets for dairy cows. *J Dairy Sci.* 1991;74:996-1005.
32. Belibasakis NG, Ambatzidis P, Tsirgogianni D, Kufdis D. Effects of dry corn gluten feed on milk production and blood components of dairy cows. *Zivocisna Vyroba.* 1986;41:111-4.
33. Bernard JK, Delost RC, Mueller FJ, Miller JK, Miller WM. Effect of wet or dry corn gluten feed on nutrient digestibility and milk yield and composition. *J Dairy Sci.* 1991;74:3913-9.
34. Ohajurka OA, Palmquist DL. Response of high-producing dairy cows to high levels of dried corn gluten meal. *Anim Feed Sci Tech.* 1989;24:191-200.
35. Macleod GK, Droppo TE, Grieve DG, Barney DJ, Rafalowski W. Feeding value of wet corn gluten feed for lactating dairy cows. *Can J Anim Sci.* 1985;65:125-34.
36. Staples CR, Davis CL, McCoy GC, Clark JH. Feeding value of wet corn gluten for lactating dairy cows. *J Dairy Sci.* 1984;67:1214-20.
37. Armentano LE, Dentine MR. Wet corn gluten feed as a supplement for lactating dairy cattle and growing heifers. *J Dairy Sci.* 1988;71:990-5.
38. Sarwar M, Firkins JL, Eastridge ML. Effect of replacing neutral detergent fiber of forage with soyhulls and corn gluten feed for dairy heifers. *J Dairy Sci.* 1991;74:1006-17.
39. Jaster EH, Staples CR, McCoy GC, Davis CL. Evaluation of wet corn gluten feed, oatlage, sorghum-soybean silage and alfalfa haylage for dairy heifers. *J Dairy Sci.* 1984;67:1976-80.
40. Johnson RR, Klosterman EW, Bently OG. Energy value of lactic acid and corn steepwater and their effects on digestibility of ruminant rations. *J Anim Sci.* 1962;21:887-91.
41. Woods W. Corn steep liquor, urea and soybean meal. Lincoln: University of Nebraska; 1970. Report No.: Nebraska Beef Cattle Rpt. EC 70-218.
42. DeFrain JM, Shirley JE, Titgemeyer EC, Park AF, Ethington RT. A pelleted combination of raw soyhulls and condensed corn steep liquor for lactating dairy cows. *J Dairy Sci.* 2002;85:3403-10.
43. Talpada PM, Gupta RS, Patel DC, Patel GR, Desai MC. Inclusion of corn steep liquor in concentrate mixture for lactating crossbred cows. *Ind J Anim Nutr.* 2002;19:91-6.
44. Turk KL, Morrison FB, Maynard LA. The nutritive value of the proteins of corn gluten meal, linseed meal, and soybean oil meal. *J Agric Res.* 1935;51:401-412.
45. Asplund JM, Nelson KS. Post ruminal biological value and limiting amino acids in corn gluten meal for sheep. *Nutr Rep Int.* 1989;40:853-61.
46. Gunderson SL, Aguilar AA, Johnson DE, Olson JD. Nutritional value of wet corn gluten feed for sheep and lactating dairy cows. *J Dairy Sci.* 1988;71:1204-10.
47. DeHaan K, Klopfenstien T, Stock R. Corn gluten feed: Protein and energy source for ruminants. 1983. Report No.: Nebraska Beef Cattle Rpt. MP-44.

48. Cavani C, Manfredini M, Breschi R. Use of maize steep liquor concentrate in the feeding of lambs. *Zootec Nutr Anim.* 1985;11:437-46.
49. Neiva JNM, Soares AN, Moraes SAd, Cavalcante ACR, Lobo RNB. Corn gluten meal in feedlot sheep diets. *Rev Ciencia Agron.* 2005;36(1):111-7.
50. Milis C, Liamadis D, Roubles N, Christodoulou V, Giouseljiannis A. Comparison of corn gluten products and a soybean-bran mixture as sources of protein for lactating chios ewes. *Small Rum Res.* 2005;58(3):237-44.
51. Hunter JE, Marble KR, Kandel HC. Vegetable protein in turkey rations. *Penn State Exp Stat.* 1935;August:13.
52. Ringrose RC, Norris LC, Heuser GF. The value of corn gluten meal for feeding poultry. *Cornell Univ Agric Exp Sta.* 1939:18.
53. Slinger SJ, Pettit JH, Evans EV. The use of corn gluten feed to replace meat meal in poultry rations. *Sci Agric.* 1944;24:234-9.
54. Babidis V, Florou-Paneri P, Kufidis D, Christaki E, Spais AB, Vassilopoulos V. The use of corn gluten meal instead of herring and meat meal in broiler diets and its effect on performance, carcass fatty acid composition and other carcass characteristics. *Arch Geflugelk.* 2002;66(4):145-50.
55. Abdel-Raheem HA, Sayed AN, Gazia NA, El-Maswary SMA. Evaluation of full-fat soyabeans and corn gluten meal as protein sources in broiler diets. *Assiut Vet Med J.* 2005;51:40-57.
56. NRC. Nutrient requirements of domestic animals: Nutrient requirements of poultry. 9th Rev. ed. Washington DC: National Academy of Sciences-National Research Council; 1994.
57. Wilkinson WS, Barbee C. The relative value of xanthophyll from corn gluten meal, alfalfa, coastal bermudagrass and pearl millet for broiler pigmentation. *Poult Sci.* 1968;47:1579-87.
58. Sullivan TW, Holleman KA. Effect of alfalfa meal, corn gluten meal and other dietary components on egg yolk color. *Poult Sci.* 1962;41:1474-8.
59. Artman NR. Interactions of fats and fatty acids as energy sources for the chick. *Poult Sci.* 1964;43:994-1004.
60. Sasse CE, Baker DH. Availability of sulfur amino acids in corn and corn gluten meal for growing chicks. *J Anim Sci.* 1973;37:1351-5.
61. Misra HP, Potter LM. Available lysine, digestible protein and metabolizable energy in corn gluten meal for young turkeys. *Nutr Rep Int.* 1978;18(2):203-15.
62. Castanon F, Leeper RW, Parsons CM. Evaluation of corn gluten feed in the diets of laying hens. *Poult Sci.* 1990;69(1):90-7.
63. Gerry RW. The value of corn gluten feed in rations for chickens. University of Maine, Orono: 1971. Report No.: Research in the Life Sciences 19(No. 1).
64. Osman M, El-Deek AA, Mervat SE, Mona AM. Productive performance of laying hens as influenced by dietary corn gluten feed plus probiotic supplementation. *Egypt Poult Sci J.* 2003;23:219-38.

65. Castanon F, Han Y, Parsons CM. Protein quality and metabolizable energy of corn gluten feed. *Poult Sci.* 1990;69(7):1165-73.
66. Owings WJ, Sell JL, Ferket P, Hasiak RJ. Growth performance and carcass composition of turkey hens fed corn gluten feed. *Poultry Sci.* 1988;67:585-9.
67. Brito AB, Stringhini JH, Cruz CP, Xavier SAG, Leandro NSM, Cafe MB. Effects of corn germ meal on broiler performance and carcass yield. *Arch Bras Med Vet Zootech.* 2005;57(2):241-9.
68. Brito, A. B. de, Stringhini JH, Belem LM, Xavier SAG, Leandro NSM, Cafe MB. Performance and egg quality of laying hens from 30 to 64 weeks of age containing integral corn germ meal. *Acta Sci Anim Sci.* 2005;27(1):29-34.
69. Tsang STL, Schaible PJ. The value of corn fermentation solubles in poultry nutrition. *Poult Sci.* 1960;39:251-7.
70. Waldroup PW, Hillard CM, Abbott WW. Evaluation of corn dried steep liquor concentrate in the diet of broiler chicks. *Poult Sci.* 1970;49:1203-8.
71. Shen TF, Marrett LE, Sunde ML, Bird HR. Growth promoting effect of condensed fermented corn extractives (corn fermentation condensed solubles) in chickens. *Poult Sci.* 1970;49(542):545.
72. Saharan KM, Qureshi MJ, Javed MY. Nutritive value of corn steep liquor as a substitute for soybean meal in broiler rations. *J Anim Plant Sci.* 1999;9(1):17-9.
73. Waldroup PW, Rutherford HO. Acceptibility of corn dried steep liquor concentrate for laying hens and turkeys. *Poult Sci.* 1971;50(6):1863-7.
74. Waldroup PW, Hazen KR. Examination of corn dried steep concentrate and various feed additives as potential sources of a haugh unit improvement factor for laying hens. *Poult Sci.* 1979;58:580-6.
75. Evvard JM. In: Corn gluten feed for fattening pigs. 1920. p. 70-4.
76. Geurin HB, Hoefler JA, Beeson WM. Protein efficiency of corn coproducts and other protein feeds for swine growth. *J Anim Sci.* 1951;10:607-10.
77. Lopez N, Chicco CF, Godoy S. Nutritive value of bran and defatted corn germ meal in pig feeding. *Zoo Trop.* 2003;21(3):219-35.
78. Moreira I, Ribeiro CR, Furlan AC, Scapinello C, Kutschenko M. Utilization of defatted corn germ meal on growing-finishing pigs feeding—digestibility and performance. *Rev Bras Zootech.* 2002;31(6):2238-46.
79. Soares LLP, Silva CA, Pinheiro JW, Fonseca NAN, Cabrera L, Hoshi EH, Silva MAA, Canteri RC. Defatted corn germ meal for swine in the growing and finishing phase. *Rev Braz Zootech.* 2004;33(6. Suppl1):1768-76.
80. Edwards SA, Prescott NJ, MacDougall DB. The effects of level of maize gluten feed in the diet of pigs on performance and carcass quality. *Anim Prod.* 1985;41:363-8.
81. Yen JT, Baker DH, Harmon BG, Jensen AH. Corn gluten feed in swine diets and effect of pelleting on tryptophan availability to pigs and rats. *J Anim Sci.* 1971;33(5):987-91.

82. Caleffi A, Broccaioli A. Beer draff and maize gluten feed in diets for fattening pigs. *Rev Suinicoltura*. 1990;31:43-5.
83. Castaing J, Coudere R, Fekete J, Grosjean F. Use of maize gluten feed for weaned piglets and meat pigs. *Journ Rech Porc France*. 1990;22:159-65.
84. Hu W, Lang Z, Wen T. Effects of corn gluten feed and corn germ feed on the performance of growing and fattening pigs. *J Jilin Ag Univ*. 2002;24(6):91-4.
85. Zimmerman DR. Research with co-products of corn wet milling fed to pigs. In: *Corn Gluten Feed for the Livestock Industry*. AS-565. Ames: Iowa State University; 1985. p. 23-5.
86. Yen JT, Brooks JD, Jensen AH. Metabolizable energy value of corn gluten feed. *J Anim Sci*. 1974;39(2):335-7.
87. Honeyman MS, Zimmerman DR. Long-term effects of corn gluten feed on the reproductive performance and weight of gestating sows. *J Anim Sci*. 1990;68(5):1329-1336.
88. Honeyman M. Corn gluten feed for swine. Iowa State University, Ames: 1985. Report No.: *Corn Gluten Feed for the Livestock Industry*. AS-565.
89. Cornelius SG, Harmon BG, Totsh JP. Condensed fermented corn solubles with germ meal and bran (DSL) as a nutrient source for swine. III. metabolizable energy content. *J Anim Sci*. 1977;45(3):482-5.
90. Harmon BG, Gato A, Pettigrew JE, Cornelius SG, Baker DH, Jensen AH. Condensed fermented corn solubles with germ meal and bran as a nutrient source for swine. II. amino acid substitution. *J Anim Sci*. 1975;40:247-50.
91. Funaba M, Matsumoto C, Matsuki K, Gotoh K, Kaneko M, Iriki T, Hatano Y, Abe M. Comparison of corn gluten meal and meat meal as a protein source in dry foods formulated for cats. *Am J Vet Res*. 2002;63(9):1247-51.
92. Funaba M, Oka Y, Kobayashi S, Kaneko M, Yamamoto H, Namikawa K, Iriki T, Hatano Y, Abe M. Evaluation of meat meal, chicken meal, and corn gluten meal as dietary sources of protein in dry cat food. *Can J Vet Res*. 2005;69:299-304.
93. Case LP, Czarnecki-Maulden GL. Protein requirements of growing pups fed practical dry-type diets containing mixed-protein sources. *Am J Vet Res*. 1990;51(5):808-12.
94. Weigel JC, Loy D, Kilmer L. *Feed Co-products of the Corn Wet Milling Process*. Washington D.C.: Renewable Fuels Association; 1997. p. 11-12.
95. Funaba M, Tanaka T, Kaneko M, Iriki T, Hatano Y, Abe M. Fish meal vs. corn gluten meal as a protein source for dry cat food. *J Vet Med Sci*. 2001;63:1355-7.
96. Kamar GAR, Samy MS, Raid SA, Maghraby N, Yamani A. Evaluation of different plant protein concentrates in rabbit feeds. *Egypt J Vet Sci*. 1999;33:61-71.
97. Aboul-Ela SS, Allam EA. Nutritional evaluation of linseed meal, sesame meal, corn germ meal, and protelan in rabbits. *Res Bull Ain Shams Univ*. 1980;1321:14.

98. Villamide MJ, Blas JCD, Carabano R. Nutritive value of cereal by-products for rabbits. II. wheat bran, corn gluten feed and dried distillers grains and solubles. *J Appl Rabbit Res.* 1989;12(3):152-3.
99. Wu YV, Rosati RR, Sessa DJ, Brown PB. Evaluation of corn gluten meal as a protein source in tilapia diets. *J Agric Food Chem.* 1995;43:1585-8.
100. Wu YV, Rosati R, Sessa DJ, Brown P. Utilization of corn gluten feed by Nile tilapia. *Prog Fish Cult.* 1995;57:305-9.
101. Robinson EH, Li MH, Manning BB. Evaluation of corn gluten feed as a dietary ingredient for pond-raised channel catfish *Ictalurus punctatus*. *J World Aquac Soc.* 2001;32:68-71.
102. Regost C, Arzel J, Kaushik SJ. Partial or total replacement of fish meal by corn gluten meal in diet for turbot (*Psetta maxima*). *Aquaculture.* 1999;180:99-117.
103. Pereira TG, Oliva-Teles A. Evaluation of corn gluten meal as a protein source in diets for gilthead sea bream (*Sparus aurata* L.) juveniles. *Aquaculture Res.* 2003;34:1111-7.
104. Kikuchi K. Partial replacement of fish meal with corn gluten meal in diets for Japanese flounder *Paralichthys olivaceus*. *J World Aquac Soc.* 1999;30:357-63.
105. Engin K, Carter CG. Fish meal replacement by plant and animal byproducts in diets for the Australian short-finned eel, *Anguilla australis australis* (Richardson). *Aquaculture Res.* 2005;36(5):445-54.
106. Schrage MP, Woody HD, Young AW. Net energy of ensiled wet corn gluten feed in corn silage diets for finishing steers. *J. Anim. Sci.* 1991;69:2204-2210.
107. Koeln L, Paterson JA. Nitrogen balance and amino acid disappearance from the small intestine in calves fed soybean meal-, toasted soybean meal-, or corn gluten meal-supplements. *J. Anim. Sci.* 1986;63:1258-1266.
108. Titgemeyer EC, Merchen NR, Berger LL. Evaluation of soybean meal, corn gluten meal, blood meal and fish meal as sources of nitrogen and amino acids disappearing from the small intestine of steers. *J. Anim. Sci.* 1989;67:262-275.



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