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CONTENTS

FOREWORD

The development of corn (*Zea mays* L.) paralleled the development of the great nations of the Western Hemisphere. Corn was a staple in the diets of the Aztecs and Incas. Its development and use by the natives and European colonists of North America and later by farmers and agricultural scientists in the USA laid a foundation of agricultural development upon which this great nation was built.

In the USA, corn emerged as a major feed crop for both domestic use and export, thus providing abundant, high-quality animal products for consumption in many nations. More recently, corn has become an important raw material for producing industrial products, such as ethanol.

Even after centuries of development, there is still great untapped potential in the corn crop. In this book, world authorities on corn describe its past development and forecast its future possibilities. The authors were chosen carefully to represent many different perspectives and areas of expertise. They represent both the seasoned veterans and the rising stars of corn research and development.

This book will serve as a valuable research and teaching reference. It provides a base of knowledge from which to launch new research efforts on corn improvement, production, and use. Hopefully, it will stimulate an expanded effort to exploit the full potential of this great species.

We particularly appreciate the efforts of Drs. George F. Sprague and John W. Dudley of the University of Illinois in performing the many duties associated with editing this book. They have made it a truly exceptional volume, one that will serve as the definitive work on corn and corn improvement for many years into the future.

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(Hanson, 1946) with variable but mostly positive results (often not statistically significant). Published feeding trials comparing waxy corn to regular corn on poultry, swine, lamb, and dairy and beef cattle have been reviewed by McDonald (1973) and Hicks (1979). They concluded that although some results gave no improvement or negative results, small but positive results were usually found. On the average, daily gain was greater and less feed was consumed per pound of live weight gain for the animals fed waxy corn. Many of the inconsistencies in results may have been due to poor control over quality of either the waxy or the regular corn used, and most did not make comparisons between isogenic hybrids. Nevertheless, many farmers have been growing and feeding waxy corn with positive results. Testimonials indicate increases in daily rate of gain with swine plus lower back fat and better grade. Dairymen are pleased with finding up to 12% increase in milk production and 10% increase in butter fat content. Beef cattle and sheep also are said to have shown profitable rate of gain and feed efficiency (Marking, 1987).

15–3.2 Formulated Feeds

Specialization in agricultural production has given rise to a feed industry which has shown remarkable growth in volume and sophistication over the past 60 yr. Sales of formulated feeds amounted to $10.5 billion in 1982 (USDC, 1984). Ash et al. (1988) have estimated U.S. production of all manufactured feed at 89.63×10^6 t (98.8×10^6 tons) of which 86.96% are classed as primary feed and 13.04% as secondary feeds (feeds made by adding a small amount of another ingredient to a primary feed). Primary feeds are of two types, complete feeds and supplements (including concentrates and premixes) to which a producer adds his own grain. The supplements amounted to 19.8% of all feeds and use about the same ratio of cereal grain to other ingredients as do complete feeds. Complete feeds were more important for poultry and dairy while supplements were used in larger volumes for beef and swine. Complete feeds made up 78.9% of the 1984 reported volume of primary feeds. The total number of feed mills in the USA in 1984 was 6600, but 27 of the largest mills (>100 000 tons annual capacity) produced 40% of the formulated feed volume (Ash et al., 1988). About one-third of the feed manufactured was fed to the producer's own livestock, but in the Southeastern states, where much of the broiler industry is located, 70% of the feed is fed to the producer's own livestock. By-product feeds from wet and dry milling of corn were used in feed formulation at a level of 1.9%, wheat mill feeds amounted to nearly 6%, and distillers feeds and brewers grains at 1.8% (USDC, 1984). Oilseed meals constituted 18.3% of primary feeds. Formerly the majority of feed was ground and fed in mash or meal form, but in 1984 53.1% was fed as pellets, up from 41.7% in 1975. An additional 4.2% was offered as cubes, 0.6% as blocks, and 5.6% in liquid form in 1984, leaving 36.5% fed in meal form (Ash et al., 1988).

Feed manufacturers use parametric linear computer programming in feed formulation (Enochian et al., 1971). With this method, the formulator uses weekly prices of all possible ingredients and determines their value on the basis of average composition for all needed nutrients in a particular formula. Ratios of ingredients are then adjusted to provide a feed product of desired composition at the lowest price. The new weekly formula is then transmitted to the computers that control blending of ingredients at the manufacturers plant(s). Practically all feed is now delivered in bulk carriers, generally trucks operating within a 50 to 75 mile radius of the mixing plant.

Manufacture of dog, cat, and other pet foods continues to expand and become more sophisticated. Sales in 1982 were $4.44 billion, up 44% from 1972 (USDC, 1984). These products provide convenience and good nutrition (Rhodes, 1975). Cooked and extruded corn or corn meal, cornflakes, corn gluten meal, and corn gluten feed are important ingredients in pet foods.

Although the major contribution of corn to any feeding system is energy production, its contribution to the protein content of feeds is estimated to be about 25% of total protein in complete foods. This estimate includes protein contributed by the corn by-product feeds. Corn protein is easily digested by all animals and has a high level of the S-containing essential amino acids, cystine and methionine. It is deficient in the essential amino acids, tryptophan and lysine, needed for optimum growth (Wright, 1987). Soybean meal is the major source of tryptophan and lysine, but is deficient in S amino acides. The achievement of a highly efficient animal agriculture owes its existence not only to a great expansion in the knowledge of nutrition in the last 50 to 60 yr, but also to the development of soybean as a major crop. Soybean not only took up the farmland released by the rapid expansion of corn yields, but have provided a low-cost companion feed material with corn. Soybean meal makes up about 17% of the volume of formulated feeds (USDC, 1984).

15–4 WET MILLING

The wet milling process, from its modest beginning about 1840, has developed into a highly sophisticated means of separating the components of the corn kernel by chemical and physical methods into a multitude of useful products. Since that date, the wet milling industry has experienced continued improvement in operating efficiency and product quality, continued expansion in variety and utility of products, and growing demand for its products. During the 10 yr from 1974 to 1984, corn used for wet milling increased 152% (Livezey, 1985). This phenomenal growth was made possible by development of a process for enzymatically converting glucose to fructose in 1961 (Hebeda, 1987). Sweetness equal to sucrose was achieved with introduction of a High Fructose Corn Syrup (HFCS) containing 55% fructose and 45% glucose in the late 1970s. Acceptance of this product for soft drinks accelerated production of HFCS in the early 1980s (Table 15-4) and in 1985 consumption of corn sweeteners for the first time exceeded sucrose consumption in the USA. (ERS, 1986f, 1987). Recovery of markets following the recession of 1982 to 1984, and participation by some wet milling companies in the government supported fuel ethanol programs has raised the utilization of corn by this industry to record levels. In the 1986–87 crop year, it consumed 21.58×10^6 t (850×10^6 bu) amounting to 10.3% of the corn produced or 16% of the domestic disappearance. Projections indicate that wet milling will utilize 25.4×10^6 t (1 billion bu) by 1990 (Corn Refiners Association, 1987). In the last 20 yr, the wet milling industry has adopted new technology resulting in plants that are highly automated and computer controlled (May, 1987). Since major markets for starch and sweeteners are nearly saturated, prices are highly competitive, and since major new product introductions are not close to commercialization, growth in the next decade will probably be closer to the pre-1970 average of 2 to 4% per year (Leath and Hill, 1987). This industry has reached a new plateau of maturity but through continued research and development of new markets, steady, undramatic growth can be expected.

Currently, 20 operating wet milling plants exist in the USA and probably over twice that number in other countries. Total world corn use in wet milling is not accurately known but may amount to as much as 50 $\times 10^6$ t.

15–4.1 The Process

The wet milling process is outlined in Fig. 15–1. The industry's raw material is shelled corn generally purchased as U.S. No. 2 or with appropriate cash discounts for any factors exceeding requirements for U.S. No. 2. Specialty corn-types, waxy and high amylose, are purchased by identity preserved contracts. Before the corn enters the plant, it is inspected for U.S. Grade factors, freedom from aflatoxin, insect, and rodent infestation; unfit shipments are rejected (Freeman, 1973). Accepted lots are thoroughly cleaned by screening and aspiration. Cleanings are added to the by-product feed. The clean corn is then steeped for 30 to 35 h at 47 to 35°C to soften it for the initial milling step. Steeping is more than just soaking corn in water. It is a complicated biochemical process (Watson, 1984). The corn is steeped in stainless steel tanks arranged in batteries of 8 to 12 steeps connected in series by pipes. Water is moved by pumps from one steep to another in a countercurrent relationship with respect to another in a countercurrent relationship with respect to the corn. Process waters are continually reused by operating the entire process in a countercurrent manner. Fresh water is introduced only at the final starch-washing step and works its way stepwise countercurrently to the flow of milled corn, picking up increasing levels of soluble materials. The resulting process water containg 1 to 2% solubles is dosed with 0.10 to

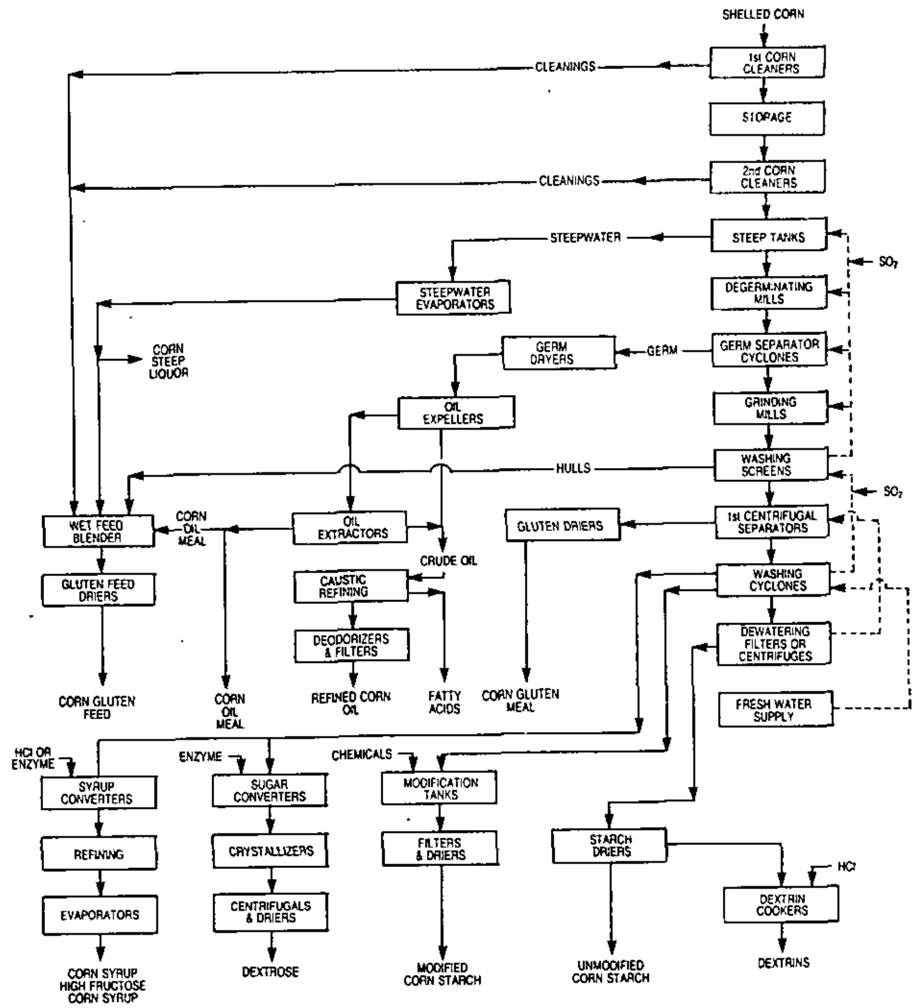

Fig. 15-1. Wet milling process for corn.

0.20% sulfur dioxide (SO_2) which is placed on the corn that has been in the battery the longest time, i.e., the corn that is nearly ready for milling. The oldest water is withdrawn at a solubles concentration of 5 to 7%, dry basis (db). It is evaporated to the thick, brown, corn-steep liquor, 50 to 55% dry substance, composed of protein, peptides, amino acids, lactic acid, and minerals. This fraction represents about 7.5% of the original corn dry substance. About half of this material was originally water soluble; the other half was solubilized during steeping by action of native grain enzymes and SO_2 on protein. The solubilizing action of SO_2 on endosperm protein is essential for softening the kernel for optimum starch recovery (Watson and Sanders, 1961). About half of the steepwater dry substance derives from the germ and half from the endosperm. Final steepwater contains 26% db of the lactic acid content derived by fermentation of sugar leached from the corn by indigenous lactic acid bacteria (Watson et al., 1955). The steep temperature is maintained between 47 to 53°C to favor growth of these bacteria. This temperature and the pH of 3.9 to 4.2 produced by the lactic acid inhibits growth of undesirable organisms.

The milling and separation steps are, of course, somewhat different for individual milling plants but, in general, all follow the steps shown in Fig. 15–1. They have been described in detail elsewhere (Watson, 1984; May, 1987). In the initial milling step, fully steeped corn at about 45% moisture (wet basis) is passed through an attrition (cracking) mill, along with some water, for the purpose of liberating germs with minimum germ breakage. Simultaneous to germ release about one-half of the kernel starch (prime starch) is released in this step. The germ fraction, which now contains about 50% oil (db), is separated from the denser components by flotation in continuously operated liquid cyclones. The germ is washed and dried in preparation for oil recovery.

The underflow from the liquid cyclones is further milled in vertical plate attrition-impact mills or in impact pin mills. However, one company recovers only the prime starch for further purification, while the remaining bound starch is saccharified and fermented to ethyl alcohol (Smith et al., 1966).

After the endosperm has been finely milled, starch and gluten particles must be separated from the residue. This is accomplished by passing the slurry over a series of screen-bend devices that are comprised of stationary curved metal surfaces perforated by precisely milled slots 70 to 80μ in width. At least one reslurry step is required to produce optimum starch yield. The fiber overflow is then usually dewatered in a continuous screw press and dried alone or in mixture with steepwater to produce corn gluten feed.

The starch and gluten particles in the screen underflow are separated in continuous centrifugal machines, usually of the disc stack nozzle-type. The lighter gluten particles are discharged with most of the water into the overflow while the heavier starch granules are discharged into the underflow. The gluten is concentrated and filtered using rotary vacuum filters. The filter cake is dried in flash or rotary hot air dryers to produce 70% protein corn gluten meal at a yield of 5.5 to 6.0% of corn, db. The recovered water is used for fiber washing or steeping.

The starch slurry must be further purified to a final protein content of about 0.3%. This is usually accomplished by diluting the starch slurry with fresh water and passing it through a series of liquid cyclones. The starch cyclones, 1 cm in diameter and 15-cm long, are assembled into a shell which provides for starch slurry introduction, purified starch underflow, and gluten and solubles overflow. The advantage of using the (5–7) cyclone units in series is that they accomplish gluten separation and starch washing simultaneously. The starch is washed countercurrently, finally being contacted with the fresh water entering the milling system (Fig. 15–1).

Starch may be dried by several different methods, but the most economical is with flash dryers. Starch slurry is dewatered by filtering or centrifuging and the cake discharged into stream of heated air. The starch is dried in only a few seconds; flash dryers operate at high volume and low cost. For the manufacture of hydrolyzed products or the manufacture of chemically modified starch products, finished starch slurry from the final cyclone stage is used directly. Although many of the specialized starches are sold in paper bags, most of the large tonnages of commercial starch is transported in hopper cars loaded and unloaded by air fluidization.

Continuing research and engineering developments have transformed the wet milling operation into a highly automated, continuous process (May, 1987). All phases of the unit operations are monitored by instruments which feed data into central control panels. The process may be operated from these control rooms by activating remote control valves, tank level controls and motor switches, and by automatic measurement of density and flow rates. The combination of continuous flow, precise control, closed stainless steel tanks, and careful sanitation has transformed "corn grinding" into a scientific food-processing operation. Continuous progress has been made over many years by the wet milling industry to minimize water and air pollution. Approximately 99% of the initial corn dry substance is recovered as useful products. The unrecoverable remainder is rendered harmless to the environment by modern sewage treatment and smoke abatement procedures.

15–4.2 Starch Products

The primary product of wet milling is starch. It is recovered in purified form in a yield of 67 to 69% of corn dry substance with a recovery efficiency of 93 to 96% of the contained starch. Nearly one-fourth of the corn starch produced is sold as starch products; more than three-fourths is sold as hydrolyzed products, corn syrups, and dextrose. Although starch sales (Table 15–7) increased since 1976, sweetener sales have increased more rapidly due to the impact of development of sweeter syrups. Total U.S. starch sales in 1982 were 2.485×10^6 t (5478.9×10^6 lb) of which corn was 91.75%, while other starches, including potato (*Solanum tuberosum*), tapioca (*Manihot utilissima* Pohl), wheat (*Triticum* spp.), and rice (*Oryza sativa* L.) starches, were 8.25% (USDC, 1984).

15–4.2.1 General Properties and Applications

Industrial corn starch is a fine white powder, 99% pure, containing only about 0.25 to 0.3% protein, <0.1% minerals, and 0.65% fat. The fatty components of starch are tightly complexed with the starch molecule

Table 15-7. Quantity of wet milling products sold.

Product description	Quantity 1976†	1982†	1986†
	1000 t		
Starch products§	2 489	2 281	2 211
Sweeteners, total			
Glucose syrups	2 144	2 302	3 226¶
Dextrose	575	580	NA
High Fructose corn syrup			
42% fructose	1 453	2 067	2 631
55% fructose¶	--	1 696	4 502
Corn oil (crude and refined)#	284	401	540
Corn gluten feed	2 263	3 905	4 389
Corn gluten meal	479	826	816
Steep liquor	NA	NA	150
Other by-products (Including seepwater)	260	480	NA
Exports not otherwise included	--	–	70
Total accounted for	9 947	14 538	17 995

† USDC (1984) except as noted.
‡ Data from Corn Refiners Assoc. (1987) plus 10% to account for wet millers not in the CRA.
§ Includes regular and modified starches, and dextrines.
¶ Includes a minor volume of 90 and 100% fructose products.
# ERS (1986d).

and are composed of 55 to 63% free fatty acids, 25 to 38% lysophospholipids and a small amount of other lipids (Morrison and Milligan, 1982).

Corn starch is an important manufactured product because of its usefulness in many industrial applications. Although a few uses depend on properties in the dry state, most applications relate to its properties as a cooked, hydrated paste. The industrial and food applications of corn starch are many and space in this chapter allows for only a cursory description. For more detailed information, the reader is referred to one of the comprehensive treatises available (Orthoefer, 1987; Smith and Bell, 1986; Whistler et al., 1984; Russell, 1973).

Corn starch occurs naturally in nearly spherical granules of 5 to 30 μ in diameter (avg. diam of 14μ). The granules are composites of crystalline and amorphous aggregates of two distinct molecular types, amylose and amylopectine, both of which are polymers of α-D-glucose. Amylose comprises about 27% of the corn starch granule. It is a linear polysaccharide composed of 1000 to 10 000 glucose residues connected by α-1,4 glucosidic linkages. The more abundant amylopectin, 73% of the granule, is a large bush-like molecule with short α-1,4 linked chains connected by α-1,6 glucosyl branching linkages (French, 1984).

Raw starch granules exhibit a maltese cross birefringence pattern when observed microscopically with plane polarized light. Their most striking characteristic is the ability to absorb water and swell within a narrow specific temperature range known as the gelatinization temperature range (GTR). At the beginning of the range a few granules lose birefringence and at the end-point temperature 98% of the granules have

lost birefringence known as the birefringence end-point temperature (BEPT). The GTR is characteristic for each starch species but it is influenced by crop production environment (Freeman et al., 1968). Regular corn starch extracted from corn grown in the Midwest typically has a GTR of 62 to 72°C. Chemicals added to a starch slurry and/or chemical alteration of the starch granule can dramatically alter the GTR and the BEPT (Leach, 1965). Raw corn starch absorbs about one part water for two parts starch, but at the BEPT water absorption increased to 20-fold. As a result, the granule swells proportionally and continues to increase in volume as temperature is raised above the BEPT. In this condition, the granule is easily disrupted mechanically or is hydrolyticlaly degraded with acid or enzymes. A direct result of granule swelling is a parallel increase in starch solubility, paste viscosity, and clarity (Zobel, 1984; Leach, 1965).

Adhesion of the swollen granules and binding of water cause a large increase in viscosity. The application of shear to the swollen granules with continued cooking causes marked reduction in viscosity and increased clarity and solubilization. When the paste is cooled, viscosity again quickly increases to an even greater degree accompanied by increased opacity. The transformations are known as gel formation and retrogradation. These properties along with adhesiveness, film-forming ability, and digestibility combined with low cost, are what make corn starch such a useful material in the manufacture of food and industrial products.

Much of the research and development activity of major starch producers has been to modify starch in such a way as to optimize desirable and minimize undesirable properties for a particular commercial application. Most commercial starch products fall into one of the following categories; (i) unmodifed starch, (ii) acid-modified starch, (iii) dextrins, (iv) oxidized starch, (v) cross-linked starch, (vi) chemical derivatives of starch, and (vii) pregelatinized starch. Various combinations of these categories are also produced.

15–4.2.2 Unmodified Starch

Unmodified corn starch, also called *mill starch* or *thick-boiling starch*, is the largest volume and lowest cost industrial starch product amounting to about 60% of all corn starches produced. It is used where its properties of high paste viscosity, strong gels, and retrogradation are useful or can be tolerated. Charcoal briquette molding, beneficiation of bauxite ores, and dusting powder are examples. Paper and paper product manufacture comprise the largest industrial uses of raw starch, consuming about 60% of all starch sold. It is used as an internal binder in forming the paper sheet, as a coating to modify surface characteristics, and as an adhesive in manufacture of paperboard (Mentzer, 1984; Kennedy and Fischer, 1984). More than 22 × 10^6 t of paper and 25 × 10^6 t of paperboard were produced in 1982 and production is increasing at about 4.5% a year (USDC, 1984).

For most uses in paper, unmodified starch must be thinned by jet cooking or by enzyme thinning as the paste is made at the mill. This improves adhesiveness and increases production rate (Mentzer, 1984). Numerous chemical modifications of starch are manufactured to reduce paste viscosity, increase adhesiveness, increase retentiveness on fibers, and reduce setback to prolong working time. In food applications, chemical modifications are made to improve texture in foods, to increase clarity, to reduce gelatinization temperature, to improve emulsification properties, to increase solubility, etc. A starch can be made that will fit almost any use. New varieties are introduced every year which improve food quality and production efficiency (Moore et al., 1984; Smith and Bell, 1986).

15–4.2.3 Acid Modified Corn Starch

Granular acid-modified, thin-boiling starches are prepared by heating granular starch slurry below the GTR with acid. The random hydrolytic action is stopped by neutralization at a point that will give the desired paste thinness, and the starch is washed and dried. Cooked pastes of acid-modified corn starches have lower viscosities than mill starch but have a stronger gelling tendency. The lowered viscosity permits use of pastes at higher dry substance. In many uses, such as adhesives for paper lamination and clay coating, the starch must be incorporated at high solids content. In other uses, such as textile warp-sizing applications, where smooth, strong film coatings are needed to protect the fibers during weaving, acid-modified starches are preferred (Compton and Martin, 1967). The greater gelling tendency of acid-modified corn starches gives desired set and texture in gum confections (Wurzburg, 1970).

15–4.2.4 Maltodextrins and Pyrodextrins

"Dextrins" are degradation products of starch covering a wide range of properties and made by a variety of methods (Satterthwaite and Iwinski, 1973). Maltodextrins are prepared by the hydrolytic action of α-amylases on waxy (preferred) or regular starch pastes to the extent of producing 5 to 20 dextrose-equivalent (DE) products of complete solubility but little or no sweetness (Katz, 1986). Maltodextrins are instantly soluble in water, giving clear to hazy solutions of low viscosity. They are completely digestible and completely bland. They contribute body in frozen desserts, soups, etc.; they are excellent carriers for spray drying hygroscopic solids such as instant tea and coffee; they have excellent protective colloid action for fats and are major constituents of coffee whiteners; they are bland diluents for artificial sweeteners, etc. In dry mixes, low DE maltodextrins keep package contents free flowing.

Pyrodextrins are produced by the action of dry heat with or without the presence of (hydrochloric) acid. Pyrodextrin products have a wide range of properties and uses, but are used predominantly in the nonfood industries (Satterthwaite and Iwinski, 1973). The low conversion products, known as *white dextrins*, are made in a broad range of solubilities. Clarities of solutions increase and viscosities decrease with increasing solubility. The high-conversion yellow dextrins are completely soluble and produce clear, nonhazing solutions of low viscosity. Major applications for pyrodextrins are in adhesives for fabricating paper products of all kinds (Kennedy and Fisher, 1984) and for remoistenable gums such as on postage stamps and packaging tape, sizing and finishing textiles, thickeners for water-soluble, fabric-printing inks, and filler for rug backings. Use in foods is limited but is quite acceptable from a regulatory standpoint even though digestibility of the high conversion types is lower than starch. Uses are found in the pan coating of hard candy and to thicken emulsions.

15–4.2.5 Oxidized Starches

Another type of thin boiling starch, oxidized corn starch, is prepared by treating starch slurry with sodium hypochlorite solution. The hypochlorite treatment not only bleaches and causes limited hydrolysis but it also forms some carboxyl and carbonyl groups by oxidation of free hydroxyl groups (Rutenberg and Solarek, 1984). This results in a lower gelantinization temperature, improved ease of dispersion, improved paste clarity, and reduced setback or gel formation. Paste of oxidized starch, when spread in a thin layer, dries to a clear, adherent, continuous film providing the kind of properties desired for paper sizing, paper clay-coating adhesive, textile warp size for cotton and rayon, and laundry finishing, including aerosol spray starch. Lightly bleached starches find use in tableting certain pharmaceuticals such as aspirin and in some food uses such as batters and breadings. A small amount is used in manufacture of wallboard, and acoustical tile.

15–4.2.6 Pregelatinized Starches

The trend toward prepared home and bakery mixes, precooked foods, water-soluble laundry sizes, and many other convenience, items, require starch preparations that will form pastes in cold or warm water. These may be prepared by drying pastes on heated rolls, by spray drying, or by simultaneous pasting and drying on the rolls (Smith and Bell, 1986). Any type of modified starch may be prepared in this manner, but waxy starches are preferred because of easier reconstitution in water. These products are often difficult to disperse in water because all granule structure has been destroyed and particles tend to surface-paste with dry centers. Recently a granular, cold water swelling form has been developed by high-temperature treatment in an aqueous alcoholic solution (Eastman and

Moore, 1984; Smith and Bell, 1986) which simultaneously destroys the granule crystalline structure and removes free and complexed lipids (Jane et al., 1986). The instant solubility and different past viscosity properties may provide new applications for cornstarch.

15–4.2.7 Chemical Derivatives

Bifunctional reagents like glyoxal, epichlorohydrin, phosphorus oxychloride, and metaphosphates can react with 2 mol of hydroxyl to form linkages binding adjacent starch molecules. The degree of cross-bonding regulates the degree of swelling of the starch granule and the tolerance to viscosity loss in acidic conditions (Leach, 1965). Waxy starch must be cross-linked for use in foods to reduce peak viscosity and limit viscosity loss from shear and acidity while retaining the clarity and lack of setback. Cross-linked waxy starches are now used to thicken fruit pie fillings and prepared foods of all kinds. Heavily cross-bonded corn starch is used for dusting surgical gloves which must be autoclaved; the starch will not gelatinize but is slowly digested in the body (Wurzburg, 1970).

Monofunctional chemical reagents that react to form ester or ether linkages with hydroxyl groups in starch are a means of adding substituent groups which may radically alter the physical and chemical properties of starch. Most commercially produced chemically modified starches have a degree of substitution of <0.2, i.e., reaction with only one hydroxyl on every fifth glucose unit. A great number and type of chemical starch modifications are possible. For more details, the reader should consult Rutenberg and Solarek (1984), Orthoefer (1987), and Wurzburg (1986).

Hydroxyethyl starch, made by reacting ethylene oxide with starch, is probably the largest volume derivative. The hydroxyethyl group lowers gelatinization temperature and makes for stable pastes that produce clear, flexible films on drying (Rutenberg and Solarek, 1984). It is popular as a textile warp size and in liquid laundry starches. Hydroxyethyl acid modified corn starch is used in paper sizing and clay coating, and for thickening of high gloss printing inks. A highly substituted hydroxyethyl starch has been used as a blood plasma extender. Hydroxypropyl starch is FDA approved for use in thickening foods such as salad dressings.

Corn starches with cationic groups such as amino alkyl and quaternary ammonium starches have found broad use as internal binders in paper manufacture (Russell, 1973; Mentzer, 1984). They disperse readily in hot water to give smooth, stable pastes. They are strongly absorbed by the negatively charged paper pulp and, although higher in price, can be used at dosages of 0.5% on a dry pulp basis compared with 2 to 3% for unmodified starch. The cationic starches are also useful as flocculating agents in purification of industrial water and ore benefication.

15–4.2.8 Waxy Starch

The waxy endosperm mutant (*wx*) was investigated by scientists at the Iowa Agricultural Experiment Station as early as 1936. They recognized that waxy corn starch properties were somewhat similar to those of tapioca starch and began to develop waxy hybrids. Wet milling possibilities were recognized by Hixon and Sprague (1944), and commercial production began soon thereafter (Shopmeyer et al., 1943). The wet milling properties of waxy corn (waxy maize) are similar to regular corn but starch properties are quite different from regular cornstarch. Waxy starch granules are similar in size and appearance to granules of regular corn starch but are composed entirely of the branched starch fraction, amylopectin (Shannon and Garwood, 1982). Waxy granules can be readily identified by observing a reddish purple coloration when stained with dilute I_2-KI solution instead of the intense blue color of regular starch or higher amylose starches. The unique properties of waxy starch pastes are attributable to absence of amylose. The GTR of waxy corn starch is a little higher than for regular starch; the swelling power when cooked at 95 °C is 2.66 times greater but with the same degree of solubiliziation. For this reason unsheared, waxy starch pastes exhibit high initial viscosity when freshly pasted but on shearing drop below the viscosity of similar regular corn starch pastes, especially under acidic conditions (Leach, 1965).

Waxy starch pastes are long and cohesive, whereas regular corn starch pastes are short and heavy bodied. Waxy starch pastes have a much greater degree of clarity than normal corn starch and tend to remain clear on cooling because of the absence of retrograding amylose. For the same reason, waxy starches do not gel on cooling but remain as fluid, redispersible sols. Waxy starch pastes, dried in thin layers, form translucent films that are readily redissolved. These properties make waxy corn starch useful in many food and industrial uses. However, in nearly all of these uses the properties must be modified by chemical or physical means to increase utility. The clarity and stability of amylopectin starch gels make them especially suitable for thickening fruit pies and many prepared, canned, and frozen foods (Wurzburg, 1970). Chemical cross-linking is necessary to restrict granule swelling and prevent viscosity breakdown on cooking; derivatization with phosphate, acetate, succinate, or hydroxypropyl groups increase paste clarity after repeated cycles of freezing and thawing (Rutenburg and Solarek, 1984).

Thin boiling, oxidized, and hydroxyalkyl modifications of waxy starch produce improved film clarity for textile sizing and certain types of paper coating. Waxy corn starch is the preferred starting material for maltodextrins because of improved water solubility after drying and greater solution stability and clarity. Waxy pyrodextrins have superior remoistening characteristics. Application for modified and unmodified waxy corn starches has continued to grow especially in response to consumer demands for more ready-prepared food items. Powell (1973) has provided a good review and a comprehensive list of applications for the waxy (amylopectin) starches.

15–4.2.9 Higher-Amylose Starch

The recessive endosperm mutant *ae* produces starch containing 55 to 60% amylose named *amylomaize* or high-amylose corn as described in Chapter 14 in this book. Subsequent breeding has produced modified *ae* types having up to 85% amylose. Amylomaize hybrids were initially developed by the Bear Seed Co., Decatur, IL, but are now produced by Custom Farm Seeds of Momence, IL. The commercial utilization was pioneered by two wet milling companies, National Starch and Chemical Corp. and American Maize Products Co., in the early 1960s. Wet milling of high-amylose corn gives lower starch yields than regular corn (Anderson et al., 1961).

Amylomaize starch granules are of two distinct types, spherical and irregular, and are smaller than normal starch granules. The BEPT is reported as 97 °C but they have a high, broad GTR (Shannon and Garwood, 1984). Some of the granules do not lose all birefringence even after prolonged boiling; swelling power is only one-fourth and solubles one-half that of regular corn starch at 95 °C (Leach, 1965). However, pastes prepared by jet steam cooking alone or in the presence of alkalies, salts, or formaldehyde can be handled commercially if not allowed to cool and can be used where tough, opaque films are valued. Hydroxyethyl and hydroxypropyl derivatives improve solution stability of amylomaize starch. Young (1984) has listed 56 applications of unmodified and chemically modified amylomaize starch. Its uses of greatest importance are sizing of glass fibers prior to weaving; a component of gummed candies; preparation of a clear, hot water dispersible, edible film for packaging foods, dyes, and other soluble materials; and coating paper to reduce water and fat absorption. Amylomaize starch sales are small but growing, especially in Europe.

15–4.3 *Sweetener Products*

The corn wet milling industry began in the mid-19th century as a producer of corn syrups, known for many years as glucose syrup or just glucose. Corn syrup has remained an important sweetener ingredient in foods, along with sugar. Corn syrups and crystalline glucose (dextrose) are less sweet than sucrose and therefore have normally brought lower prices. Glucose (dextrose) is the six-carbon monosaccharide that is the basic monomer comprising the starch molecule, and is the major source of energy in human and animal nutrition. The name *dextrose* refers to the crystalline commercial product. Wet milling companies now produce a syrup that has comparable sweetness to sucrose using an enzyme that isomerizes glucose to fructose. Coming at a time of scarcity and high price of sucrose in the early 1970s, the new high fructose corn syrup (HFCS) triggered a new round of expansion of wet milling facilities and entry of new producers into the business (Table 15–7). Since HFCS syrups can be produced and sold profitably at lower prices than sucrose, they have taken a significant share of the sweetener market. In 1985 to 1986, corn sweeteners for the first time in history, made up more than 50% of the U.S. sweetener market, an increase from about 10 to 11% prior to

1970 (Corn Refiners Association, 1987; Hebeda, 1987). This increase has been made possible due to U.S. government sugar crop support programs and import restrictions that maintain a price above world sugar prices.

15–4.3.1 Corn Syrups

In the time-honored method of manufacturing corn syrup, a 35 to 40% starch slurry is acidified with hydrochloric acid to 0.15 *N* and heated under pressure to 140 °C. Syrup properties are controlled by stopping the reaction by neutralization at the desired dextrose equivalent (DE). The hydrolyzate is purified by removing insolubles, decolorized by treatment with activated vegetable carbons, and in some cases deashed by passage over ion exchange resins. It is then evaporated to syrups with densities of from 40 to 46 ° Baume which correspond to 75 to 86% dry substance. The process is thoroughly described by Hebeda (1987).

Syrup properties are determined by the DE and by the sugar oligosaccharide components which can be analyzed by high performance liquid chromatography (HPLC) (Hobbs, 1986). Important functional properties include viscosity, sweetness, fermentabiliy, humectancy-hygroscopicity, colligative properties, and participation in the browning reaction. As DE increases, sweetness, fertmentability, and browning increase because of increases in dextrose, maltose, and maltotriose contents. Viscosity, an important property in many food systems, declines as DE increases. Following acid hydrolysis, saccharide composition can be further modified by treatment with various enzymes to produce desired functional properties (Hebeda, 1987).

The syrups consumed in largest volume at the present time are the standard low-priced 42 DE acid-converted syrup, and the 58 to 73 DE high fermentables noncrystallizing syrups produced for the brewing trade (Table 15–6). The latter syrups are made by converting a medium DE (40–50) acid syrup with a fungal diastase-type enzyme that will hydrolyze some higher saccharides (Newton, 1970). Syrups with high maltose are made from acid-thinned paste (15 DE) converted with malt. The enzyme technology now available permits manufacture of syrups with many different proportions of the sugars. Combinations of these products with or without sucrose provide an inifinite number of food applications.

The largest volume uses of corn syrup are in confections, followed by bakery and dairy products. Syrups provide a body to hard candies giving them chewiness and desirable mouthfeel without excessive sweetness; hygroscopicity of hard candy can be reduced by use of high maltose syrup (Frey, 1967). Corn syrups also act as foam stabilizers in marshmallows and provide desired humectancy to maintain plasticity, and they produce desirable viscosity in thick fruit syrups such as in canned peaches (Newton, 1970). Corn syrups are used in baking and in brewing as a source of fermentable carbohydrates. The more highly converted syrups produce freezing point depression for frozen desserts and osmotic concentration for food preservation. The lower converted products help control the number and size of sugar crystals in fondants, ice cream, icings, jams and jellies, and sheen in fruit preserves and pie fillings.

About 5% of the corn syrup sales are in nonfood uses such as bodying agents in inks, shoe polish, textile finishes, adhesive formulations, and pharmaceuticals; in tanning leather; as humectant in tobacco. Low (20–30) DE syrups can be dried (corn syrup solids) for use in foods where water input must be limited.

15–4.3.2 Dextrose

Fully converted starch hydrolyzates (95–96% dextrose) are now universally prepared from acid or enzyme (α-amylase) thinned starch pastes by incubation with amyloglucosidase, an enzyme of fungal origin (Hebeda, 1987). The hydrolyzate is refined and concentrated as for corn syrup and is introduced hot into crystallizers containing a large amount of seed crystals from a previous batch. The mixture is slowly stirred and cooled over a 3 to 4-d period. The crystals are recovered and washed in a basket centrifuge and dried (Schenk, 1986). It is also sold as a 71 dry wt. liquid and shipped in heated tankers. The anhydrous alpha form is produced by recrystallizing a solution of dextrose hydrate in a "strike" evaporator pan at 60 to 65 °C. Anhydrous dextrose is used in pharmaceuticals and food systems, such as dark, sweet, or milk chocolate products, and where the presence of water cannot be tolerated. The U.S.P. grade dextrose, which is used for intravenous feeding and other therapeutic uses, is produced by dissolving and recrystallizing centrifuge cakes to obtain high purity. Dextrose sales have declined slowly in the last 20 yr (Table 15–6).

Functional properties of dextrose include sweetness, fermentability, browning, and osmotic pressure. Dectrose crystals have a negative heat of solution and give a mouth-cooling flavor release. In dry or liquid form, dextrose is about 76 and 65 to 70%, respectively, as sweet as sucrose (Hanover, 1982).

Confectionery manufacture uses account for about 10% of the dextrose produced, mainly as a major component of tableted candies, chewing gum, gum confections, fondants, and hard candy formulations. Another large use for dextrose is in canning and frozen food packs, catsup, frozen desserts, prepared dry mixes, prepared icings, jams, jellies, and preserves, pickles, meats, soft drinks, wines, and malt liquors. The largest single use is in baked goods where the dextrose serves as a yeast nutrient, provides some sweetness, and produces crust browning.

It is used as a tableting aid and diluent, and large tonnages are converted yearly to sorbitol by hydrogenation. Sorbitol is used in the production of synthetic vitamin C and as an intermediate in other chemical syntheses. Dextrose is an excellent carbohydrate source in fermentations for citric acid, antibiotics, etc. (Hebeda, 1987).

15–4.3.3 High Fructose Corn Syrup

A corn syrup composed of 42% fructose (levulose) and 58% glucose (dextrose) is made by reacting fully converted starch hydrolyzate with the enzyme glucose isomerase, contained within cells of several different microorganisms. Whole cells or isolated enzymes are attached to solid particles, such as alumina, and the starch hydrolyzate is passed over columns of the immobilized enzyme for continuous isomerization. The syrup is refined before and after isomerization (Hebeda, 1987).

Since hydrolyzed sucrose solutions (invert syrup) are approximately 55% fructose, competition required development of equivalent corn syrups. This was accomplished chromatographically by passing 42% fructose syrup through columns of adsorbent containing Ca or other divalent anionic groups (Long, 1978), or a mineral adsorbent (Broughton et al., 1977). Fructose is retained on the adsorbent more strongly than glucose. Elution washes off glucose which is recycled to isomerization columns. Final elution is 90% fructose which is evaporated and sold as such (Young and Long, 1982) or, more generally, blended with 42% isomerate to produce a 55% fructose syrup. Additionally, pure crystalline fructose is now being commercially produced by chromatographic separation to obtain a 97% fructose fraction for crystallization (Hebeda, 1987; ERS, 1986e).

Properties of HFCS are similar to those of regular corn syrups but sweetness is its foremost property. Crystalline fructose is 1.8 times sweeter than sucrose and 2.4 times the sweetness of crystalline dextrose (Hanover, 1982). The 55% HFCS has the same sweetness as sucrose while the 90% HFCS is 6% sweeter, but sweetness perception is affected by temperature, pH, and concentration. Other studies have shown that sweetness comparisons in complicated food systems are often different from comparisons made from water solutions of sugars and are greatly affected by concentration. Hence, HFCS has equal sweetness to sucrose in some foods; in others it is less sweet. Thus, HFCS has found application in a wide variety of food systems such as confections, baked goods, table syrup, fountain syrups, sweet beverages, catsup and other condiments, pickles, etc. (Young and Long, 1982). A major marketing goal from the beginning was to obtain acceptance in all carbonated beverages. This goal was achieved in 1982 through improved quality standards, improved processing, and refining methods (Morris, 1984). Acceptance of HFCS for 100% of sweeteners by major bottlers gave a large boost to corn wet milling volume (Table 15–4) and produced a mature marketing environment capped by establishment of a futures market for HFCS on the Minneapolis Exchange in March, 1987 (ERS, 1986e).

15–4.4 Feed Products

Kernel components, mainly protein and fiber, remaining after recovery of the corn starch and corn oil in the wet milling process amount to about one-third of the original corn dry substance (Fig. 15–1). These materials are sold almost exclusively as ingredients in feeds for farm animals and pet foods (Wright, 1987). The corn gluten meal (CG) is standardized at 60% protein, and contains about 400 mg/kg in xanthophyll pigments at the beginning of a crop year. However, xanthophyll content drops gradually through the year due to oxidation in corn processed, reaching about 200 mg/kg of CG by the end of the season (Watson, 1962). Corn gluten meal is used primarily as a protein concentrate and pigment source in broiler chicken feeds (Kuzmicky, 1968) in areas where yellow skin is a desirable marketing attribute. It is important as a protein source high in essential S amino acids, methionine and cystine in poultry, swine, and pet rations (Wright, 1987). Soybean meal compliments the low levels of lysine and tryptophan in gluten meal while CG makes up for the deficiency of S amino acids in soy. In cattle and sheep, CG is only partially digested in the rumen providing essential amino acids through duodenal digestion (by-pass protein) (Klopfenstein et al., 1985). Corn protein purified in such a way as to have bland flavor is a potential source of vegetable protein for food in combination with soy and other proteins (Neuman et al., 1984).

The wet milling fraction, containing the corn pericarp or "fiber," is composed mostly of cellulose and hemicellulose plus residual starch and protein. It has a digestibility of 80% (total digestible nutrients, TDN) for ruminants and is sold by one wet milling company at a 10% protein level for ruminant and dairy rations. Several companies are refining the pericarp fraction to give a bland food fiber source containing up to 90% dietary fiber. Most of the wet milled fiber, however, is blended with steepwater and spent corn germ flakes or expeller cake and dried to 10% MC to produce corn gluten feed (CGF). This product has a standardized protein guarantee of 21% and finds use primarily as a major ingredient in dairy and beef cattle rations, but can also be used at up to 10 to 15% in laying chicken and swine rations, respectively. Versions of CGF having higher steepwater contents at up to 31.5% protein are available from several companies and may be more suitable for nonruminant animals because of a lower proportion of fiber. In recent years, wet CGF has been sold directly to cattle feed yards as a way to reduce air pollution and energy costs (Wright, 1987). Fortunately, CGF is highly regarded as a feed ingredient by the Dutch who import 80% of the U.S. production for European feeds. About 4.6×10^6 t of by-products were produced by the industry in 1986 compared with only 1.33 t in 1972.

Corn germ meal containing 22.5% protein is available from wet millers who solvent extract corn germ. It is useful in feeds as an absorbent for liquid ingredients such as molasses, fish solubles, choline, etc. Corn steep liquor or heavy steepwater is known officially as a feed ingredient by the name "condensed fermented corn extractives." It is sold to a limited extent as a component of liquid feeds for beef cattle, as a component in beef range blocks, and as a fermentation nutrient (discussed

under Fermentation Industries, section 15–12). Corn steepwater is rich in phytin (hexaphosphoinositol) from which the vitamin, i-inositol, has been manufactured.

15–4.5 Corn Oil

Corn oil is commerically produced only from corn germ isolated by wet milling or dry milling. Because of this supply restriction combined with strong demand, corn oil usually commands a slightly higher price than the other two major vegetable oils, soybean, and cottonseed. The volume of corn oil produced has steadily increased over the last half century as wet and dry milling capacity has expanded. In 1972, the total corn oil volume reached 226 800 t (500 million lb); in 1986 the production had grown to about 612 123 t of (1.35 million lb) which 20% is exported. The dry milling process accounts for about 10% of the corn oil production. In the USA, corn oil is 4.3% of vegetable oil production and about 7.2% of domestic oil utilization (ERS, 1986c, 1986d).

Oil is recovered from corn germ by expelling, solvent extraction, or a combination of expelling and extracting as generally described by Reiners and Gooding (1970); Orthoefer and Sinram (1987). Wet milled germ is preferably expelled from an oil content of 50 to 60% down to 20 to 25% and finally extracted with hexane to a residual oil content of 1 to 2% in the spent corn germ flakes. Most dry corn mills recover oil only by extraction or sell germ to those who extract.

Crude corn oil is composed of 95% triglycerides. Minor components include free fatty acids, waxes, phospholipids, pigments, and odorous compounds, which must be removed by refining to achieve an acceptable food product. In outline, this process involves several steps: (i) forming the sodium soaps of the free fatty acids, (ii) removing the emulsion containing the soaps and the phosphatides by centrifugation, (iii) removing the waxes by chilling, (iv) removing pigments by contact with bleaching clays, (v) removing odors by high-vacuum distillation at 225 to 260 °C. The fatty acid fraction is recovered by heating the emulsion in the presence of sulfuric acid and is sold as an ingredient for use in beef and poultry rations (Orthoefer and Sinram, 1987).

Refined corn oil is 98% triglycerides in which the saturated constituent fatty acids are palmitic (16:0) 11.0%, stearic (18:0) 1.8%, and arachidic (20:0) 0.2%. The unsaturated fatty acids are linoleic (18:2) 60.9%, oleic (18:1) 25.3%, and linolenic (18:3) 1.1% (J.M. Hasman, 1986, CPC International, Union, NJ, personal communication). It is well known that variation in the ratio of the two principal fatty acids, oleic and linoleic, is due to genetic background as discussed in Chapter 14. The linoleic and oleic acid contents of commercial corn oil have gradually changed from 56 and 30% to the present ratio of 61 and 25% over a period of 40 yr (Weber, 1987; Reiners and Gooding, 1970) during which period total oil in corn processed at Illinois wet milling plants dropped from about 4.9 to 4.3%, apparently due to gradual changes in higher-yielding corn hybrids planted (Watson, 1987a).

The recognized acceptance of corn oil as a food oil is, in part, due to its flavor stability during storage and cooking, without added synthetic antioxidants. This stability is the result of an adequate level of natural antioxidants, the tocopherols, and a low level of linolenic acid (Weber, 1987). About 60 to 65% of the corn oil in the USA is consumed as salad or cooking oil (ERS, 1986d). Its bland flavor and high smoke point are mainly responsible for its popularity. Another reason for the popularity of corn oil is its high content of unsaturated fatty acids recognized by medical authorities (American Heart Association, 1968) as a dietary method of reducing blood cholesterol levels. The other large use, 30%, is in margarine. Corn oil margarine has grown from its introduction in 1957 to a major food item at about 11% of all margarine oils (ERS, 1986b). Other food uses are minor. The only part used industrially is the 7 to 8% removed from crude oil by refining.

15–5 DRY MILLING

The dry corn milling industry began as numerous small mills scattered across the country-side to supply whole ground corn meal to local clients for household uses. As the population became more urbanized, the demand for food products with longer shelf life resulted in the development of milling systems that produced low fat cornmeal by removal of germ. As the degermination dry milling process became more complex, mills became larger and fewer. Brekke (1970) reported that there were 152 dry corn mills in 1965 with daily capacity of 2268 kg (50 hundred-weight). At last count (Anonymous, 1984a), the number of mills had declined to 88 in 1984. Of these, 66 were small mills in Southern states and California (two). Of the larger dry corn mills, 17 account for most of the output. Twelve of these are large mills with capacities between 254 and 1778 t/d (10 000–70 000 bu) for an annual grind of 2.82 $\times$ 10^6 t (111 $\times$ 10^6 bu), which is 92% of the reported industry capacity of 3.05 $\times$ 10^6 t (120 $\times$ 10^6 bu) (Alexander, 1987). Dry milling, unlike wet milling, has maintained a nearly constant production rate at 3.0 to 3.5 $\times$ 10^6 t (118–138 million bu) annual rate.

15–5.1 The Process

As mentioned previously, the normal dent corn kernel is comprised of the following parts: pericarp, tip cap, germ, horny endosperm, and floury endosperm (Table 15–3). The degerminated corn dry milling process, more accurately called the *tempering degerminating* (TD) system, is outlined in Fig. 15–2. This process is operated to make as complete a separation of these parts as is economically possible: (i) retaining the maximum amount of horny endosperm portion as discrete pieces; (ii)

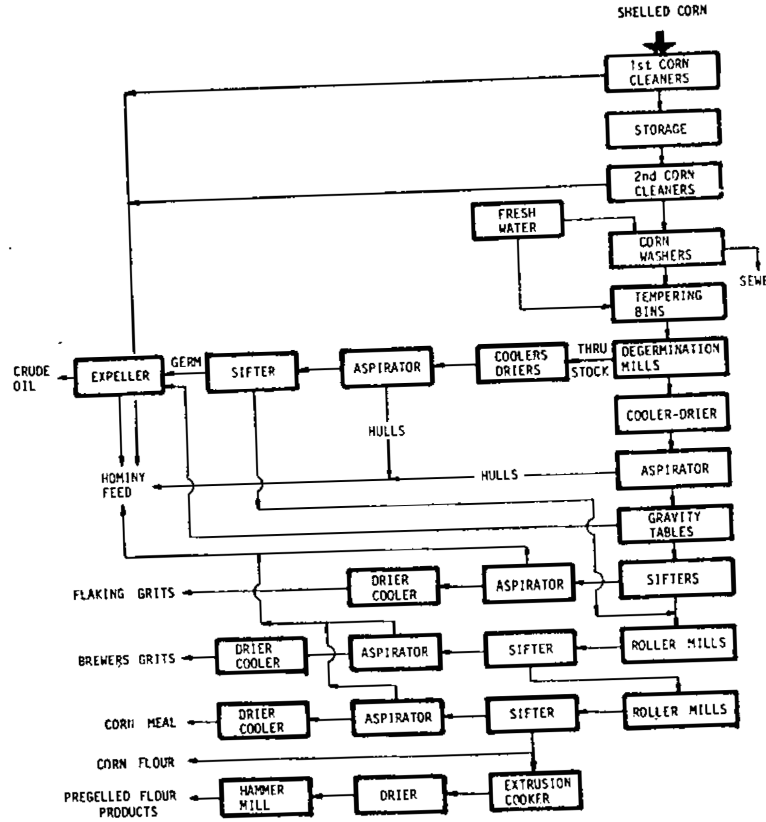

Fig. 15–2. Dry milling process for corn.

removing as completely as possible the germ and pericarp to give a low fat, low fiber product; (iii) recovering as high a percentage of the germ as large, clean pieces. Different steps in the separation process include cleaning, tempering by water addition, degerming, drying, cooling, grading, aspirating, grinding, sifting, and packaging. The corn used is usually purchased only after a sample has been inspected for freedom from aflatoxin, insects, mold, and in some plants, low breakage susceptibility (Watson, 1987b). The flow sheet (Fig. 15–2) shows how these steps are normally coordinated. However, this diagram is much simplified because separations are not perfect and fractions have to be remilled, reclassified, and resifted several times to try to achieve optimum yield and quality. Furthermore, mills differ markedly in the types of equipment used and preference for materials routing (Brekke, 1970; Alexander, 1987; Anderson and Watson, 1982).

The initial cleaning steps for the whole corn are of utmost importance because, although high-quality corn is purchased for food production, residual contamination must not be allowed to enter the process. Although not shown in Fig. 15–2., most mills use magnetic separators to remove tramp metal; scourers and aspirators to remove adhering dust, glume, and other light material; screens to remove large and small foreign material; water washing with flotation to remove cob pieces; and settlers to remove stones and nonferous metal. Some mills have used electrostatic separators to remove rat pellets the same size as corn kernels.

The cleaned corn must be tempered with water or steam to condition the corn for milling. The corn is moistened with water in an amount needed to bring the corn up to 20 to 22% moisture and held for a period of time (1–3 h) to allow the water to equilibrate through the kernel. Degermination may be accomplished in a variety of ways but the most popular, especially if flaking grits are desired, is with the Beall degerminator. Some companies use impact mills or granulators for degermination for different results with and without tempering (Brekke, 1970).

Discharge from the degerminator is dried to 15 to 18% moisture and cooled. It is sized over stacked coarse sifters or reels with the largest material +3.5 to +10 mesh passing through aspirators to remove free pericarps and thence to specific gravity tables where germs are separated from endosperm by difference in density. Endosperm fractions and impure germ-endosperm mixtures are passed through corrugated counter-rotating roller mills to remove adhering pericarp and/or germ pieces and flatten germ pieces for better screening. Each roller mill set is preceded by an aspirator to remove light material and followed by a sizing device, usually stacked screens of appropriate sizes for the stock being handled. The roller mills are set with differential speeds and a gap appropriate for the material it receives to minimize grit breakage. Endosperm fractions are finished in purifiers designed to remove fine pieces of fiber and are packaged according to grade at 12 to 14% moisture.

15–5.2 The Products

Finished germ, containing 18 to 27% oil depending on the mill configuration, is dried to 3% moisture and the corn oil expelled in standard oil expelling equipment followed by solvent extraction to a residual oil content of 1 to 2% (Brekke, 1970; Reiners and Gooding, 1970). The germ residue is blended with pericarp fractions, unseparable mixtures of endosperm, pericarp and germ, and corn cleanings to give a commodity feed item known as hominy feed (Table 15–8). This product is guaranteed to have a minimum level of 10% protein and 5% oil but generally averages 10.5% protein and 6.0% oil. Hominy feed is used as an ingredient of swine, ruminant, and poultry feeds as a source of energy and good-quality protein (Wright, 1987). Solvent-extracted germ has been processed to a germ flour containing 25% protein using a process developed by a USDA laboratory (Blessin et al., 1972). This material has become a useful, nutritious food ingredient.

A typical yield of products from dry milling are: hominy feed, 34%; corn oil, 2.0%; grits, meal, and flour, 60%; shrinkage, 4.0%. There are no definite specifications which closely define all products which can be manufactured, but the classifications generally accepted in the industry are shown in Table 15–8. The ratio among endosperm fractions varies with the quality of the corn, the milling conditions, and the orders the miller has to fill; most mills are quite flexible in the latter. Fat content is the most generally used criterion of purity. Fat values in Table 15–8 are minimum values and are affected by milling conditions and corn quality.

Table 15-8. Typical yields and products from dry corn milling.†

Product	Yield	Size (U.S. Sieve)	Fat	Protein
	%	%, db‡		
Hominy or cereal flaking grits	12	−3.5 + 6	0.7	8.4
Coarse grits	15	−10 + 14	0.7	8.4
Regular or medium grits	23	−14 + 28	0.8	8.0
Coarse or granulated meal	3	−28 + 50	1.0–1.2	7.6
Cones or dusted meal	3	−50 + 75	0.8–1.5	7.5
Corn flour	4	−75 + Pan	1.5–2.5	6.6
Corn oil§	2	–	100	--
Hominy feed	34	--	6.0	12.5
Shrinkage	4	--	--	--

† Brekke (1970). ‡ db = dry basis. § Solvent extracted.

The grit fractions are all produced from the horny endosperm, have a bright yellow color or are clear white, and are free of dust and bran pieces. The miller usually tries to optimize yield of flaking grits because of premium price. Each hominy grit will become one corn flake. A common alternate distribution of products, depending on sales needs, is to produce brewers common grits by combining larger than 24-mesh material and milling so that 95% will pass 12-mesh. All material passing 24-mesh may be sold as cornmeal, but screen size up to 32-mesh is used in some mills. Quality of grits are judged on color, odor, fat content, and freedom from dust, pericarp, and insect fragments. Flour has long been considered a by-product which at times was put in feed. However, new uses have been found that have channeled all output into more profitable markets (Roberts, 1967).

Most mills make specialty products utilizing raw grits, meal, or flour. These raw materials are processed by cooking with steam to the desired degree of starch gelatinization, on flaking rolls or extrusion cookers, dried and ground as required by the user (Alexander, 1987). The degree of dispersibility of these products is conditioned by the particle size of the starting material, method, time, and pH of cooking, and degree of shear.

15–5.3 Uses for Corn Endosperm Products

Utilization of the approximately 2.857×10^6 t (6.299×10^9 lb; adjusted for noncorn ingredients) of dry corn products manufactured are distributed among human foods, beverages, pet foods, and industrial products are shown in Table 15–9.

Of the 1.86 × 10^6 t of endosperm products, 45% is used by the brewing industry. Although brewing is the single largest use, all food uses account for 39.3%. The most commonly recognized use, particularly in Southern states, is boiled grits served as a side dish with nearly all meals. Some people prefer the bolder flavor of yellow corn products especially in the northern USA, however, most people, especially in Southern states, prefer white grits; more than 80% of the table grits sold are white. Corn bread or corn muffins made from cornmeal have long been a favorite bread in all parts of the USA, and more recently these popular dishes have been offered as dry, self-rising mixes for easier preparation. Another favorite food is corn flakes. The flaking grits are cooked to a rubbery consistency with syrup, malt, salt, and flavoring added. After tempering, the cooked grits are flattened between large steel rolls followed by toasting in traveling ovens to a golden brown color (Rooney and Serna-Saldivar, 1987). Corn products are made into several other forms of ready-to-eat cereals alone or blended with other grain products (Fast, 1987).

The rapid growth of dry mix formulations and snack products of various kinds has increased demand for corn flour to the extent that mills sometimes must increase flour yield by milling larger sized fractions. Corn

Table 15-9. Estimated 1977 product volumes of the corn dry-milling industry.†

Application areas	Quantity
	t × 10^{-3}
Brewing, total	838.98
Food, general	
Breakfast cereals and cooked grits	362.8
Mixes (pancake, cookie, muffin, etc.)	45.35
Baking	22.68
Snack foods	45.35
Other foods (breading, batters, baby foods, etc.)	34.03
Total	510.19
Fortified foods (PL 480), total	219.9‡
Nonfood	
Gypsum board	45.35
Building products (particleboard, fiberboard, plywood, etc.)	18.14
Pharmaceuticals/fermentation	90.70
Foundry binders	40.82
Charcoal binders	34.01
Other (paper, corrugating, oil well drilling fluids, etc.)	11.34
Total	240.36
Prepared pet foods§	49.43
Animal (Hominy) feed,¶ total	997.70
Total	2 856.97

† Estimates based on unpublished data (Alexander, 1987).
‡ Corn products represent 65 to 70% of total shipments, or 315 to 340 million lb.
§ USDC (1984).
¶ Data reported by Alexander (1973).

flour has been found to be particularly valuable as an ingredient of pancake mixes, baby foods, cookies, biscuits, ice cream cones, ready-to-eat cereals, batter breading mixes, and binders for loaf-type sandwich meats (Roberts, 1967). The high starch content of cornmeals and flour is important in giving a high puff in preparation of extruded snack products in which a delicate corn flavor is desired. On the other hand, isolated corn starch is most useful for snacks in which artificial flavors are to be added.

Industrial uses amount to about 13% of the dry-milled endosperm products. Most uses of corn flour are in processes where the more highly purified starches have no particular advantage even though they may be more effective on a weight basis. The major uses are foundry sand core binders, oil well drilling mud thickeners, and particle board manufacture which use pregelatinized corn flour. Unmodified corn flour is used in briquette binders; adhesive for gypsum board and other construction materials; refining and pelletizing ores; fermentation; and paperboard (Alexander, 1987). On the other hand, purified corn starches have the advantage that they can be chemically modified more specifically to fit a particular application and generally have greater adhesive power.

A food item of major importance to the dry miller in recent years has been corn-soy-milk (CSM) (Alexander, 1987) used under the Food for Peace Legislation (PL 480). This product is a mixture of 68% gelatinized corn meal, 25% defatted soy flour, 5% nonfat dry milk and 2% minerals and vitamins. A lower cost, but equally nutritious product called "corn-soy blend" (CSB) (the same as CSM except for omission of milk) has also been produced. The product has been made by companies under contract to U.S. Agency for International Development (U.S. AID). When the program began in 1966 until 1974, CSM and CSB have been distributed to more than 100 countries by the USDA. The high cost of dried milk caused a shift toward CSB in 1974. Alexander (1987) states that about 60 different products are being sent to impoverished people or local governments by private industry under contract with U.S. AID.

Corn endosperm products are also an excellent source of carbohydrate in fermentation as will be discussed in a later section. Brewers grits have long been used as a major brewing adjunct. Some breweries prefer to use a pregelatinized flake if cooking facilities are limited (Alexander, 1987).

15–6 OTHER CORN FOODS

15–6.1 Traditional Foods

Corn has been used in many parts of the world as the basic food item and people have found many distinctive ways to prepare it. For example, in the colonial and pioneer eras in the USA, traditional foods included Johnny cakes, a kind of corn bread, fried mush (cornmeal cooked, gelled,