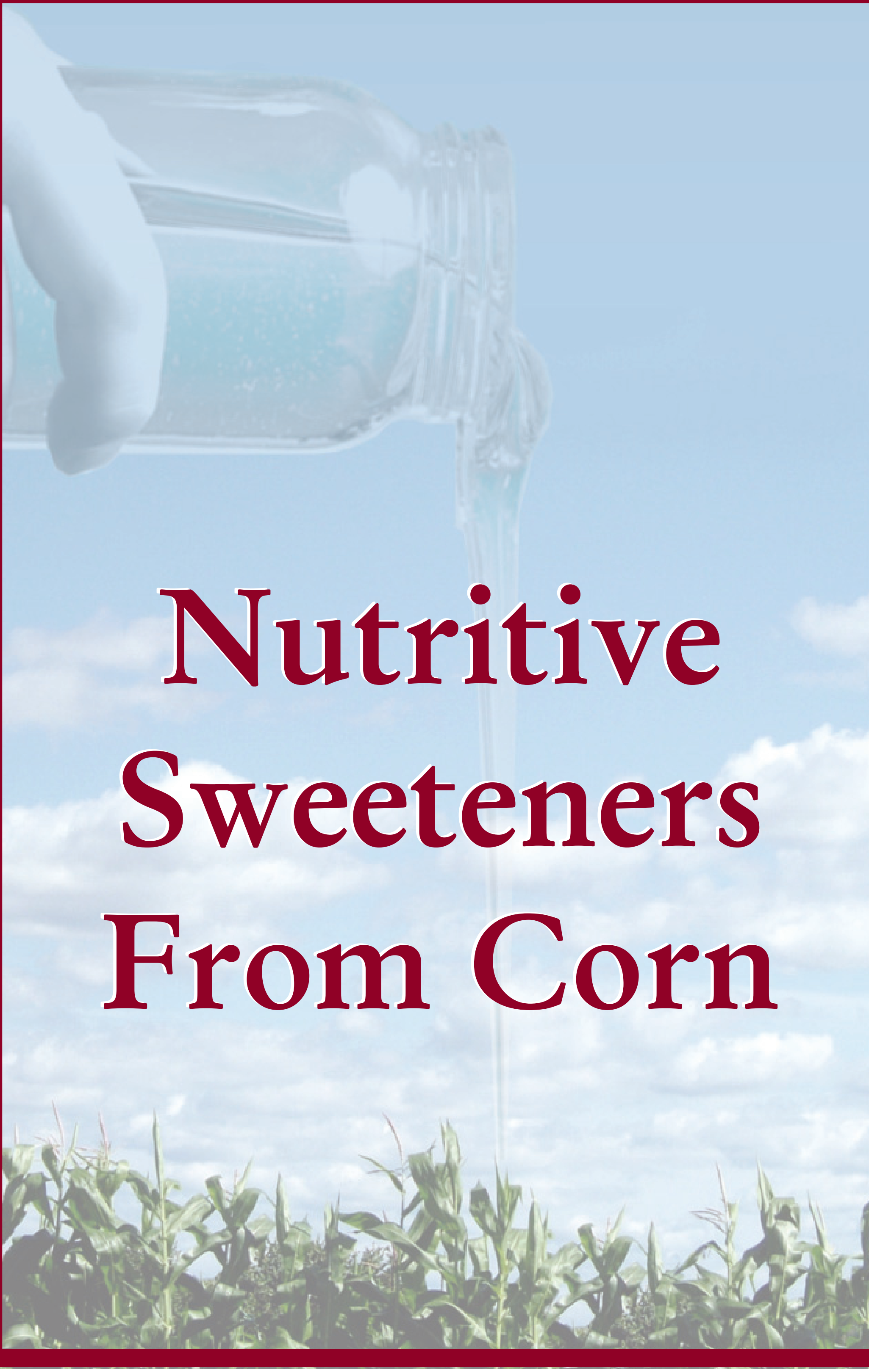

Nutritive Sweeteners From Corn

Contents

CONTENTS

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Member Companies	Plant Locations
Archer Daniels Midland Company P.O. Box 1470 Decatur, Illinois 62525	Plants: Cedar Rapids, Iowa 52404 Clinton, Iowa 52732 Columbus, Nebraska 68601 Decatur, Illinois 62525 Marshall, Minnesota 56258-2744
Cargill, Incorporated P.O. Box 5662/MS 62 Minneapolis, Minnesota 55440-5662	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
Corn Products International, Inc. 5 Westbrook Corporate Center Westchester, Illinois 60154	Plants: Bedford Park, Illinois 60501-1933 Stockton, California 95206-0129 Winton-Salem, North Carolina 27107
National Starch and Chemical Company 10 Finderne Avenue Bridgewater, New Jersey 08807	Plants: Indianapolis, Indiana 46221 North Kansas City, Missouri 64116
Penford Products Co. (A company of Penford Corporation) P.O. Box 428 Cedar Rapids, Iowa 52406	Plant: Cedar Rapids, Iowa 52404-2175
Roquette America, Inc. 1417 Exchange Street Keokuk, Iowa 52632	Plant: Keokuk, Iowa 52632-6647
Tate & Lyle Ingredients Americas, Inc. (A subsidiary of Tate & Lyle, PLC) P.O. Box 151 Decatur, Illinois 62521	Plants: Decatur, Illinois 62521 Lafayette, Indiana 47902 Lafayette, Indiana 47905 Loudon, Tennessee 37774

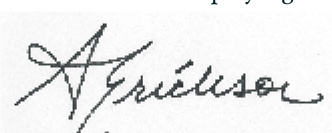
FOREWORD

The taste of sweetness stands unique among our sensory perceptions. Delving into the roots of the word "sweet," we find the Latin equivalent *suavis*—delightful—and the Greek root *Hedys*—pleasant. In Old English, these roots evolved into the word "swete," from which our present term is drawn.

Regardless of its name, humans have always sought the taste of sweetness. As the search for spices motivated earlier explorers, so has the search for sweetness moved both people and institutions.

For many years, these efforts concentrated on a tropical grass, sugar cane, and the sugar beet. But since the early 1800s, they have increasingly moved in the direction of a native American crop ... corn. Today, as this booklet details, nutritive sweeteners from corn have become America's premier sweeteners.

Many years of meticulous research have brought the corn refining industry to this point. But by no means has the search for new forms and functions for corn sweeteners ended—it will continue, and the corn refining industry looks forward to playing a central role.



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.

HISTORICAL PERSPECTIVE

The discovery that starch could be transformed into sweet substances by heating with dilute acid is nearly 200 years old. It was made in a Russian ceramics laboratory by the chemist G.S.C. Kirchoff who was seeking a substitute for the Gum Arabic that was then used as a soluble binder for clay.

Subsequent work by other scientists demonstrated that starch is a polymeric form of glucose that could be broken down to D-glucose by hydrolysis or conversion. And so the foundation was laid for a starch-derived sweetener industry.

Sweeteners were very much in the public eye at the time of Kirchoff's discovery. France was at war with Britain and cane sugar imports from the West Indies had been closed to her by the British blockade of European ports. The sugar shortage was so critical that Napoleon was under heavy political pressure to provide an alternative ingredient to satisfy the well-developed French taste for sweets. From this pressure came government financial support for investigating sugar production from both beets and grapes. "Starch sugar" attracted interest in brewing and distilling because of its high fermentability.

Though early success for sugar from the beet source appeared promising, Napoleon's defeat at the Battle of Waterloo lifted the blockade and most of the new sweetener activity ceased. Beet processing was later revived under government subsidies.

The first commercial starch hydrolysis products appeared in the U.S. in 1842 and reached significant proportions by 1857. While potatoes served as the early source for starch and syrup, dextrose (originally identified as corn sugar and called cast or chip sugar), was produced from corn starch at a plant in Buffalo, New York in 1866. In Europe, the starch industry developed principally around potato starch—derived as a by-product of a food crop—but in the United States, it flourished with the corn crop. Corn starch hydrolysis and refining furnished a major outlet for a raw material used originally in overwhelming proportion for animal feed. In drawing on the native grain as a source of industrial products for both feed and new food applications, the corn refining industry has developed a uniquely American identity and presents a remarkable chapter in man's "pursuit of sweetness."

Research and Development Orientation

From its inception, the corn refining industry has been sensitive to the needs of its customers. In its early years, much of the industry's effort was aimed at developing sweeteners with widening application and appeal. Increasing industrialization of the U.S. food system and greater understanding of ingredient functionality helped create new products and new markets. Food industry recognition that liquid sweeteners (syrups) offer ease of handling and facilitate blending to meet functional specifications increased the popularity of corn sweeteners and steadily expanded their usage.

During the first half of the 20th century, corn syrup technology advanced significantly with the introduction of enzyme-hydrolyzed products. This allowed increased control over syrup identities and properties. Two significant products were introduced that expanded the versatility of corn sweeteners. The first was the introduction in 1921 of crystalline dextrose hydrate—the end product of complete starch hydrolysis. The second was the commercialization of very low conversion products (i.e., maltodextrins) in the mid-1950s. With the addition of these two products, a wide spectrum of starch conversion ingredients was now available to the food industry.

Sweetness differences remained a major challenge to the corn refining industry until the 1970s. This challenge was met in a spectacular way by the development of commercial processes for the enzyme-catalyzed isomerization of glucose (dextrose) to the sweeter sugar, fructose (levulose). Subsequent development of separation processes for enriching the fructose content not only allowed production of syrups with higher fructose content than could be produced by enzymatic action alone, but ultimately allowed the manufacture of pure crystalline fructose from starch.

Isomerization technology enabled the industry to produce both of the simple sugars that make up sucrose and thus substantially match total invert syrup (the product of partial or complete sucrose hydrolysis). The resulting product, high fructose corn syrup (HFCS), was a development of profound significance for the food industry and the U.S. economy. Syrups of virtually any combination of viscosity and sweetness as well as other functional specifications could now be produced from corn starch.

The availability of these products made the U.S. nearly self-sufficient in its sweetener supplies, provided a major new market for America's corn producers and created thousands of new permanent jobs in the corn refining and allied industries.

The technology that allowed the production of high quality HFCS has been utilized for the production of pure fructose. Pure fructose, generally supplied in crystalline form, is twice as sweet as the dextrose from which it is isomerized; it provides economic and functional properties that are being utilized by all facets of the food industry today. The development of crystalline fructose has made corn sweeteners a viable alternative or complement to sucrose in the many products that require a dry sweetener.

Corn refiners' expertise in the areas of fermentation, microbiology and carbohydrate chemistry has enabled the industry to branch into markets traditionally served by chemical manufacturers and firms specializing in food additives. Pure strains of sugars produced through chromatographic separation combined with the enzyme technology developed to produce HFCS opened a new line of products to corn refiners. Polyhydric alcohols, or polyols, can be economically produced via catalytic hydrogenation of dextrose followed by chromatographic separation. Heretofore, production of polyols was dominated by the chemical industry, which used dextrose base material supplied by corn refiners. Polyols produced by corn refiners today include erythritol, hydrogenated starch hydrolysates, maltitol, mannitol, sorbitol and xylitol.

The most recent addition to the list of nutritive sweeteners made by corn refiners is trehalose. Trehalose is a reduced calorie sweetener produced from starch through a series of enzymatic conversions. It is a chemically stable, non-reducing disaccharide.
While polyols and trehalose

are classified as nutritive sweeteners, they are typically referred to as alternative sweeteners and have a lower caloric value than other corn sweetener products. Detailed information on the properties and uses of alternative corn sweeteners may be found on the Internet sites of individual producers. A listing of firms producing alternative sweeteners from corn may be found on the Corn Refiners Association Internet site (www.corn.org) under the "Member Companies" section.

Technology Aimed at Needs

The consumer-oriented technological development of new corn-derived products continues to direct the industry's growth as well as its potential for service to its customers. The expanded variety of corn sweeteners now available from the industry represents an outstanding example of the fruits of industrial research and development aimed at recognized consumer needs.

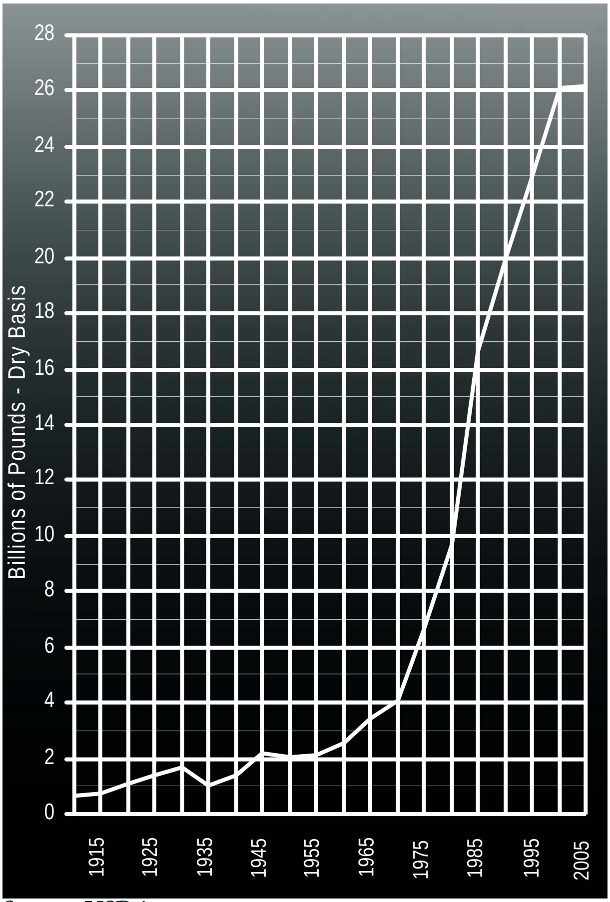
Corn refiners have applied the principles of continuous quality improvement to development of new sweetener products and processes. Application of these principles enables the industry to offer the purest, most consistent and most versatile selection of sweeteners ever available. Today's corn sweeteners are also the most economical natural sweetener available.

GROWTH, DEVELOPMENT AND DIVERSITY

The corn crop that provides the starch for corn sweeteners represents the cornerstone of American agriculture: around 10 billion bushels of corn are grown in the United States each year. During the last 30 years the corn refining industry has used an increasing percentage of this crop, and over the last five years has used about 14 percent of all corn produced in the United States. In 2005, corn refiners used approximately 1.5 billion bushels of corn. The growth rate of corn sweeteners has been most impressive. From 1960 through 2005, while the per capita annual use of nutritive sweeteners in the U.S. rose from 112 to 143 pounds, the corn sweetener market share rose from 11 to 54 percent. The curve shown in Figure 1 illustrates this growth since the beginning of data collection in 1910-1913. Of particular interest is the increased growth since the introduction of high fructose corn syrups that compete directly with sucrose and sucrose-derived products in the industrial market.

While high fructose corn syrups represent a dramatic breakthrough in sweetener technology, the corn refining industry has also been sensitive to non-sweetness functional requirements of its customers. The relative amounts of various constituent sugars such as glucose, maltose, higher sugars and polysaccharides can be varied to precise customer requirements. These variations reflect a diversity of physical properties such as viscosity, reducing sugar content, osmotic pressure, crystallization retardation, gloss, humectancy, consistency and many others valued by food and industrial scientists. Process diversification has added to the product spectrum, as have blend-

Figure 1
Corn Sweetener Shipments



Source: USDA

ing practices that allow multiple properties to be accentuated.

This breadth of choice of products and properties has broadened the uses of corn sweeteners as industrial customers have experimented with both food and non-food applications of starch conversion products. The varied uses of starch-derived conversion products are listed on pages 28 and 29.

Classification

While numerous corn sweeteners from starch of widely varying composition are manufactured, commercial products are organized into seven broad classes for official designation and are defined accordingly.

Corn Syrup (glucose syrup)—is the purified concentrated aqueous solution of nutritive saccharides obtained from edible starch with a dextrose equivalence (DE) of 20 or more.

Dried Corn Syrup (dried glucose syrup, corn syrup solids)—is corn syrup from which the water has been partially removed, resulting in granular or powdery free-flowing semi-crystalline or amorphous solid products comparable in chemical composition to their liquid counterparts.

Dextrose Monohydrate—is purified and crystallized D-glucose containing one molecule of water of crystallization per molecule of D-glucose.

Dextrose Anhydrous—is purified and crystallized D-glucose without water of crystallization.

Maltodextrin—is a purified concentrated aqueous solution of nutritive saccharides obtained from edible starch, or the dried product derived from this solution, with a dextrose equivalence (DE) less than 20.

High Fructose Corn Syrup—is a purified concentrated aqueous solution of nutritive saccharides obtained from edible starch in which a portion of the dextrose has been isomerized to fructose. It contains a minimum 42 percent fructose on a dry basis.

Fructose—is purified and concentrated D-fructose obtained from edible starch available in either anhydrous crystal or remelted liquid form.

Corn syrup, dried corn syrup, dextrose monohydrate and dextrose anhydrous are all the subject of Food and Drug Administration (FDA) food standards codified in 21 CFR 168—Sweeteners and Table Sirups. These definitions parallel those issued by the international Codex Alimentarius Commission. Maltodextrins, dextrose, corn syrup and high fructose corn syrup are Generally Recognized as Safe (GRAS) by the FDA. Specifications for corn syrup, dried corn syrup, maltodextrin, dextrose, high fructose corn syrup and crystalline fructose may be found in the *Food Chemicals Codex* published by the National Academy of Sciences. Specifications for corn-derived sweeteners in pharmaceutical use may also be found in the *U.S. Pharmacopeia/National Formulary*.

Corn Sweeteners in Nutrition

Current discussions of carbohydrates in nutrition point to an increasing role for corn sweeteners. There has been a steady decline in the complex carbohydrate content of the U.S. diet since before World War I and a concurrent, offsetting rise in fat consumption. Also, while complex carbohydrate intake, particularly of starch, has decreased, the intake of sugars has increased.

The flexibility that corn sweeteners provide in formulating syrups containing almost any mixture of simple sugars and higher polysaccharides is clear to food scientists. The ability to incorporate sweetness of almost any degree from corn sweeteners widens the range of options for formulating products to the requirements of advancing carbohydrate nutrition.

The digestion of carbohydrates begins in the mouth, with the action of salivary amylase on starch. Further digestion of mono-, di- and polysaccharides is accomplished through the actions of additional enzymes, many of which are located at the brush border epithelium of the small intestine (e.g., sucrase, lactase, maltase, α-dextrinase). The monosaccharides, such as fructose, glucose and galactose that result from the actions of such enzymes, subsequently are absorbed into the blood stream and transported to the liver or peripheral tissues for utilization by individual cells. After absorption into an individual cell, the monosaccharide is either used directly for energy production, stored as glycogen or fat to meet future energy needs, or is converted to other metabolic intermediates needed for growth and/or maintenance of body tissues.

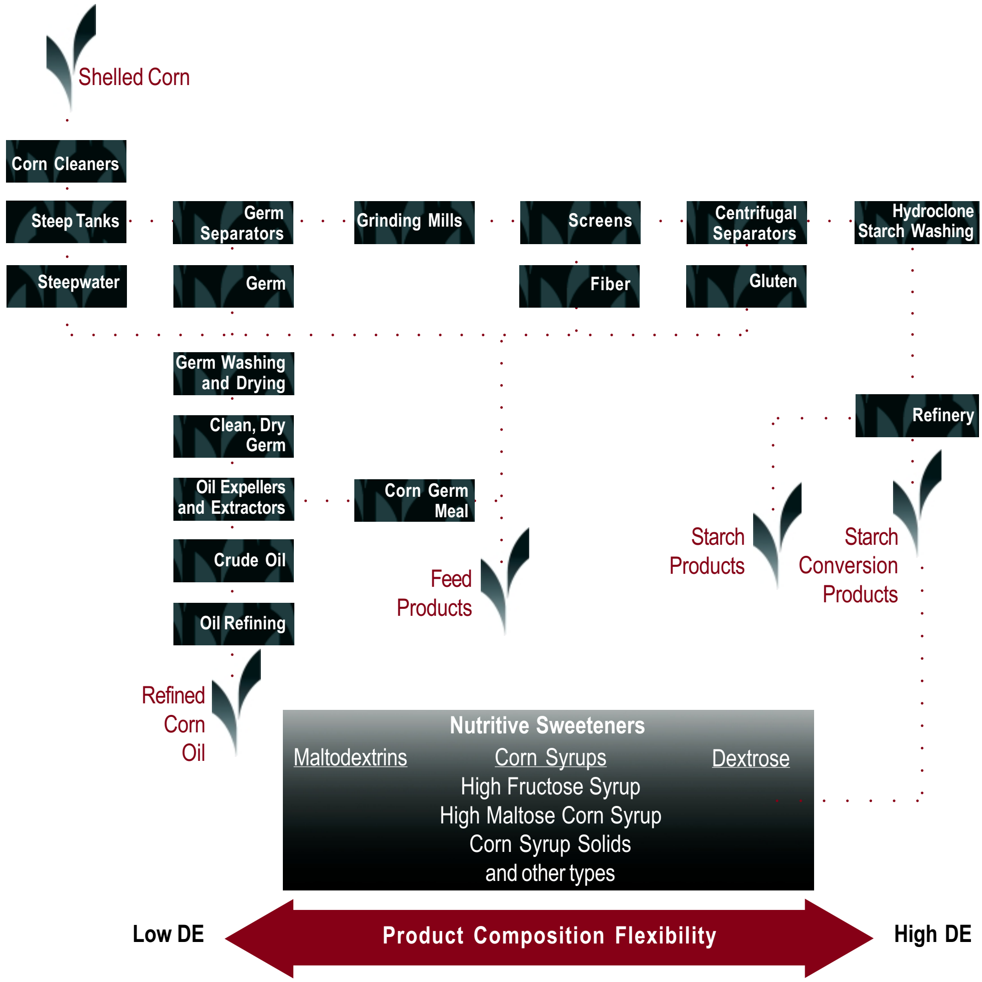
Free fructose availability in the diet increased with the introduction of HFCS 30 years ago. However, bound and free fructose availability from sucrose and invert sugar (hydrolyzed sucrose) decreased at nearly an identical rate, because sucrose was displaced from foods and beverages by HFCS. The dietary source of fructose has evolved—from fruit, to fruit-and-honey, to fruit-and-honey-and-sucrose, and finally to fruit-and-honey-and-sucrose-and HFCS—but the glucose:fructose monosaccharide ratio remains unchanged. Significantly, the source of dietary glucose and fructose is metabolically indistinguishable to the body whether it originates from fruit, honey, sucrose or HFCS.

Health and nutrition issues concerning corn sweeteners were evaluated by a special FDA task force in 1986. The FDA concluded that consumption of corn sweeteners, other than their contribution to the formation of dental caries, posed no hazard to the general public. Included in the FDA review were extensive consideration of the effect of corn sweeteners on glucose tolerance, diabetes mellitus, cardiovascular risk factors, micronutrient and trace mineral utilization, behavioral change and obesity. An extensive review of the nutritional properties of fructose and fructose-containing sweeteners covered the same health issues and reached similar conclusions. Results were published in *The American Journal of Clinical Nutrition* (Volume 58, Number 5(S), November 1993).

Corn Starch

Starch constitutes approximately 80 percent of the corn kernel and is the raw material for all corn-derived sweeteners. It is separated from other parts of corn by the corn wet milling process, illustrated in Figure 2. Cleaned, shelled corn is soaked (steeped) in a battery of tanks (steeps) in warm water containing 0.1 to 0.2 percent sulfur dioxide. The steepwater swells and softens the grain to facilitate separation of the various components. It flows counter-currently and is ultimately drawn off and replaced by fresh water. Steeped corn is degerminated in a starch-water slurry by passing it first through a shearing mill which releases the germ and then through a battery of hydrocyclones that separate the germ for oil extraction. After fine grinding, the separated endosperm and hull are screened to remove the fiber (hull). The de-hulled slurry is passed to a continuous centrifuge for starch and gluten (protein) separation. The isolated starch fraction is washed and concentrated in a series of hydrocyclones to remove nearly all of the non-starch components prior to conversion to sweeteners. As with other cereal and root starches, corn starch occurs naturally in the form of discrete granules of char-

Figure 2
The Corn Wet Milling Process



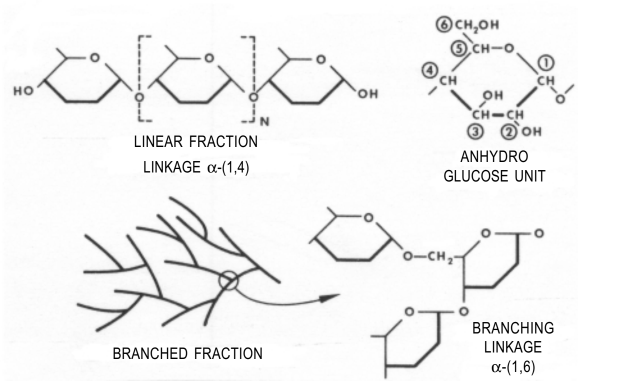


Figure 3

acteristic size and shape. These granules swell when suspended in water and heated. Ultimately they break apart to produce a paste with distinct rheological properties in which two molecular varieties of starch are dissolved or dispersed in the medium. These molecular varieties are linear starch (amylose) and branched starch (amylopectin). In corn starch, they occur in a ratio of about three parts of amylopectin to one part of amylose.

Both starch structures are condensation homopolymers or multiple aggregations of anhydroglucose molecules chemically bonded primarily in the α-(1,4) or maltose linkage. While amylose is exclusively in the linear form, in amylopectin, linear chains are organized in a tree form in which the branching point occurs in the α-(1,6) or isomaltose linkage *(see Figure 3)*.

For further discussion of the manufacture and uses of starch, see the booklet *Corn Starch* published by the Corn Refiners Association, Inc.

Starch Hydrolysis

When the linkages between the condensed dextrose molecules (anhydroglucose units) in starch chains are broken by the chemical addition of water, a reaction known as hydrolysis takes place. The ultimate product of this reaction is a simple sugar called D-glucose or dextrose. Starch hydrolysis may be catalyzed by both acids and enzymes.

Acid-catalyzed hydrolysis proceeds in a random fashion. Depending upon the conditions imposed, stopping the reaction at any particular time will yield a product comprising predictable amounts of dextrose and polymers of dextrose smaller than starch. Thus, the hydrolyzate will include some dextrose, some maltose (two dextrose units) some maltotriose (three units), some maltotetraose (four units), and so on. Corn refiners have learned how to control this reaction by varying temperature, time, catalyst and substrate concentrations so that fixed ratios of these products are obtained consistently, thus insuring the uniformity and characteristic properties of various corn sweeteners.

The industry produces many types of syrups that are most simply identified by reference to the "DE" value. The abbreviation DE stands for "dextrose equivalence," defined as a measurement of the total reducing sugars in the syrup calculated as dextrose and expressed as a percentage of the total dry substance. The method used to determine dextrose equivalence is based on the reducing action of ketose- and aldose-type sugars on specific metallic salts (e.g., copper sulfate in Fehling's Solution).

Enzymes, which are biochemical catalysts, are used by the industry to hydrolyze starch in very specific ways. For example, β-amylase breaks the starch chain at every other unit bond, producing optimal quantities of the disaccharide maltose (two dextrose units). On the other hand, α-amylase breaks the starch chain in such a fashion as to produce only minor amounts of low and medium molecular weight sugars but major amounts of soluble higher saccharides.

Glucoamylase, a third enzyme, hydrolyzes the starch chains unit by unit, producing large amounts of dextrose in the hydrolyzate.

Appropriate single or combination processes employing either acid catalysis alone, acid catalysis combined with enzyme catalysis, or combinations of different enzyme catalysis can produce almost any mixture of starch conversion products with chemical and physical properties particularly suited to specific uses.

Crystalline Dextrose

Customers have always sought purer and sweeter products. Manufacturers of corn sweeteners responded by developing crystalline dextrose. Dextrose crystallizes in two distinct forms:

at temperatures below 122 °F, monohydrate crystals are formed in which one molecule of water is bound with each dextrose molecule; at higher temperatures, anhydrous dextrose crystals are formed.

Early attempts to produce a high purity product required either repeated crystallization steps or the use of non-aqueous solvents. The only solid forms of corn sweetener available in quantity at low price before 1920 were cast products. Starch was acid-converted to as high a DE as possible, refined and evaporated to a thick syrup, and poured into molds where it solidified. It was then removed and ground into small pieces.

The development in 1921 of a process for economically crystallizing pure monohydrate dextrose resulted in a rapid growth in dextrose sales. Continued demand for increased purity led to the development of anhydrous crystalline dextrose. Dissolving monohydrate crystals provides a pure starting material. While a second monohydrate crystallization could be used to produce a chemically pure product, it was found that the anhydrous form produced a more easily separated crystal when grown from high purity solutions.

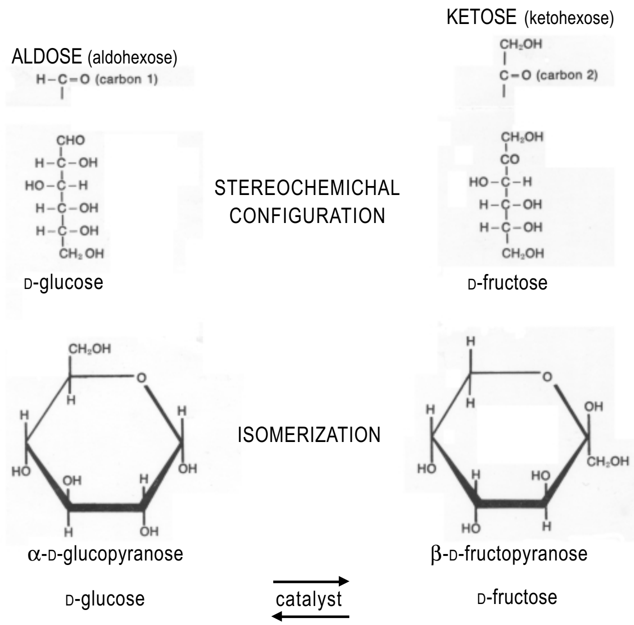
Dextrose Isomerization

Crystalline dextrose is quite pure and finds many food and industrial uses, but it is less sweet than sucrose. Although this is an advantage in some applications, its reduced sweetness limits the use of dextrose, especially in the production of carbonated soft drinks. To enter this market, a sweeter corn sweetener was needed.

Naturally occurring sugars can generally be grouped into families, the members of which have the same empirical formula. In the hexose series ("ose" is the suffix which identifies a sugar) for example, in which dextrose is the most common member, all of the sugars have the formula $C_6H_{12}O_6$. All members of the group are isomers of one another. The main differences between hexose isomers and the isomers in other groups is in the nature of the reducing group (whether aldose or ketose) and in the spatial arrangement (stereo-chemical configuration) of the atoms *(see Figure 4)*.

The property of sweetness is directly related to the struc-

Figure 4
Hexose Sugars
($C_6H_{12}O_6$)



tural differences among the hexoses. D-Fructose, a ketohexose, has a relative sweetness in the range of 120 to 160 when compared to a sweetness standard value of 100 for sucrose. Dextrose (D-glucose) is an aldohexose with a relative sweetness of 70 to 80 compared to sucrose. The corn wet milling industry was therefore very interested in a process whereby D-glucose could be converted to D-fructose.

The enzymatic transformation of glucose to fructose was introduced to corn sweetener production in 1967. The process, known as isomerization, originally involved the direct addition of an active isomerase enzyme to a dextrose-rich substrate. Later, however, batch production was replaced by a continuous process using reactors in which the isomerase enzyme is immobilized on an insoluble carrier. The production of HFCS in this manner was the first large scale use of an immobilized enzyme system.

The equilibrium conversion level of dextrose to fructose in this process is around 50 percent. However, economics dictate production at lower levels of conversion. High fructose corn syrups were first produced at a level of around 16 percent fructose, but this was quickly boosted to 42 percent fructose. The 42 percent fructose syrup can be used in most types of foods that make use of a liquid sweetener.

A "second generation" high fructose corn syrup with higher levels of fructose was made possible by development of a fractionation process that allows separation of fructose from dextrose, and subsequent concentration of the fructose fraction. Standard formulations for these products are 55 percent fructose and 95 percent fructose. The 55 percent syrup has become the standard sweetener for carbonated beverages in this country, while the 95 percent fructose syrup has wide application in many new and specialty foods. In addition, the availability of these higher (or enriched) fructose syrups has made possible the production of pure fructose and a new range of blended sweeteners that may be tailored for specific sweetening and functional requirements of food processors.

Crystalline fructose is produced by concentrating the enriched fructose fraction obtained from the separation of high fructose corn syrups, and then seeding, crystallizing and separating the pure fructose crystals from the mother liquor. Both a dry version and a liquid fructose, produced by re-dissolving crystalline fructose in water, are available.

MANUFACTURE

The manufacture of sweeteners from corn starch is a multi-step process. The starting point in the process is the conversion of starch slurry from the corn wet milling process to low solids content syrup (liquor). The starch conversion process is halted when the desired saccharide composition is reached. The starch slurry is converted in either batch or continuous converters.

Corn Syrups

The most common methods employed in the commercial production of corn syrups are the acid process, the acid-enzyme process and the multiple enzyme process. In the acid-conversion process, a starch slurry of appropriate dry substance is acidified to a pH of about 2 and pumped to a pressurized converter. The process is terminated by reducing the pressure and neutralizing the resulting liquor. Small amounts of sodium chloride are produced by this neutralization. The liquor is then clarified to remove suspended solids and is evaporated to an intermediate concentration. The intermediate syrup is further clarified, decolorized and finally evaporated to finished dry substance. While carbon treatment was the only refining method used for years, many syrups are now treated with both carbon and ion-exchange resins for further refinement.

The acid-enzyme process is similar except that the starch slurry is only partially converted by acid to a given DE. The "light liquor" is then treated with an appropriate enzyme or combination of enzymes to complete the conversion. For example, in the production of 42 DE high maltose syrup, the acid-conversion is halted at a point where dextrose production is negligible. Then a maltose producing enzyme (α-amylase, fungal α-amylase or other) is added and the conversion continued under appropriate conditions to the desired level. The enzyme is then deactivated and the purification, clarification and concentration procedures are continued as in acid-converted syrup production.

In multiple enzyme processes, starch granules are gelatinized and the preliminary starch depolymerization is accomplished by an α-amylase enzyme rather than by acid.

Various intermediate syrups of differing composition may be further converted with enzymes having distinctly different modes of action to provide specific products, such as high maltose syrups, high fermentable syrups and others.

Dried Corn Syrups

To produce dried corn syrups (corn syrup solids), completely refined corn syrups are dried in spray or vacuum drum driers. This process forms granular, semi-crystalline or powdery amorphous products. These are mildly sweet in taste and moderately hygroscopic. Because of the hygroscopicity, corn syrup solids are packed in multiwall, moisture-proof paper bags. Dried corn syrups are comparable in chemical composition to their liquid counterparts.

Maltodextrins

Maltodextrins are produced in the same manner as corn syrups except that the conversion process is stopped at an early stage to keep the DE below 20. Both acid and enzyme processes are used in their manufacture. Refining is conducted as with corn syrups. Maltodextrins are less hygroscopic because of their lower monosaccharide content and are usually spray dried to provide white free-flowing powders, packed in multiwall bags.

Dextrose Monohydrate

The manufacture of dextrose involves as complete depolymerization of the starch substrate as possible and the recovery of the product by crystallization. Starch slurry is gelatinized as in the manufacture of corn syrup and is partially converted by acid or α-amylase. Then a purified glucoamylase enzyme is added to this intermediate substrate to effect the conversion to dextrose.

The resulting liquor is concentrated, refined, cooled and pumped to crystallizers where dextrose monohydrate crystallizes from the mother liquor under carefully controlled conditions. It is separated and washed in centrifuges. The moist crystals are then dried in continuous driers to about 8.5 percent moisture. The mother liquor can be recycled and crystallized to produce a second crop of dextrose hydrate.

The moist crystals can be redissolved in pure water to produce liquid dextrose that is marketed at approximately 71 percent dry substance. Liquid dextrose is also produced by passing refined hydrolyzate through separation columns that retain dextrose while allowing higher saccharides to pass through the column. The enriched dextrose content fraction is flushed from the columns with deionized water in a process similar to that used for fructose enrichment.

Dextrose Anhydrous

Anhydrous dextrose is usually produced by re-dissolving dextrose hydrate and refining the resulting dextrose solution. This solution is evaporated to very high solids content, and anhydrous α-D-glucose is crystallized on induced or added seed crystals at elevated temperatures. The anhydrous dextrose is separated by centrifugation, washed and dried.

High Fructose Corn Syrups

In the manufacture of high fructose corn syrup, dextrose solutions or high DE substrates produced by dual enzyme processes (α-amylase plus glucoamylase or α-amylase plus glucoamylase/pullulanase) are refined by carbon and ion-exchange systems and further treated enzymatically with a purified isomerase. The isomerase reactors use an immobilized enzyme system enabling continuous isomerization and extending the life of the enzymes. Isomerization is usually carried to a point where the substrate contains 42 percent fructose. Following this step the product is refined again through carbon and ion exchange systems and is evaporated to a dry substance of 71 percent.

In the production of syrups with a fructose level above 50 percent, the original 42 percent fructose feedstock is passed through separation (fractionation) columns that retain fructose while allowing dextrose to pass through the column. This is made possible because of the natural affinity of fructose for divalent calcium immobilized on the column. Fructose retained in these columns is flushed from the system with deionized water, while the dextrose is recirculated for further isomerization. Continuous systems relying on a simulated moving bed model are utilized for this separation process. The enriched fructose fraction is generally recovered at an 80 to 95 percent purity. This product is blended with the 42 percent fructose feedstock to produce a commercial product with 55 percent fructose content. After blending, the syrup is refined again with both carbon and ion exchange systems and is evaporated to a dry solids level of 77 percent. The enriched fructose fraction may also be refined and evaporated separately for sale to users who desire a product with very high fructose content.

Fructose

Pure fructose is produced by concentrating the enriched fructose fraction obtained from the separation of high fructose corn syrups, and then seeding, crystallizing and separating the pure fructose crystals from the mother liquor. The dry version of the product is generally supplied at a maximum moisture content of 0.2 percent. A liquid fructose may also be produced by re-dissolving crystalline fructose in water to a clear, colorless product of approximately 77 percent dry substance.

GENERAL CHARACTERISTICS

The chemical, physical and functional properties of corn sweeteners vary according to their composition. To facilitate functional identity designation, corn syrups used to be classified into four types (Types I-IV) on the basis of dextrose equivalence (DE).

Type I	20 DE - 38 DE
Type II	38 DE - 58 DE
Type III	58 DE - 73 DE
Type IV	73 DE and above.

Though the 'type' designation has largely fallen into disuse, the classification of corn syrups by DE remains useful today, since syrups within classes share certain physical and functional properties.

Fructose-containing products are not classified according to DE. Rather, they are identified by their fructose content (i.e., 42%, 55%,

Table I
Compositional Data

		Saccharides, Carbohydrate Basis			
Designation	Ash	DP1	DP2	DP3	DP4+
28 DE	0.3	8	8	9	75
36 DE	0.3	14	12	11	63
34 HM *(a)*	0.3	9	34	24	33
43 HM	0.3	8	33	19	40
43 DE	0.3	19	15	12	54
43 DE Ion Exchanged	0.03	19	14	12	55
53 DE	0.3	28	20	10	42
63 DE	0.3	36	31	11	22
63 DE Ion Exchanged	0.03	36	31	13	20
66 DE	0.3	40	35	8	17
95 DE	0.3	96	2.5	0.5	1
95 DE Ion Exchanged	0.03	96	2.5	0.5	1
HFCS 42	0.03	96	2.5	0.5	1
HFCS 55	0.05	96	2.5	0.5	1
HFCS 95	0.03	99			
Crystalline Fructose	0.05	100			

(a) high maltose
DP_n = Degree of polymerization
DP_1 = Monosaccharides (dextrose, dextrose + fructose in HFCS, fructose in crystalline fructose)
DP_2 = Disaccharides, primarily maltose
DP_3 = Trisaccharides, primarily maltotriose
DP_{4+} = Oligosaccharides, maltotetrose and higher saccharides

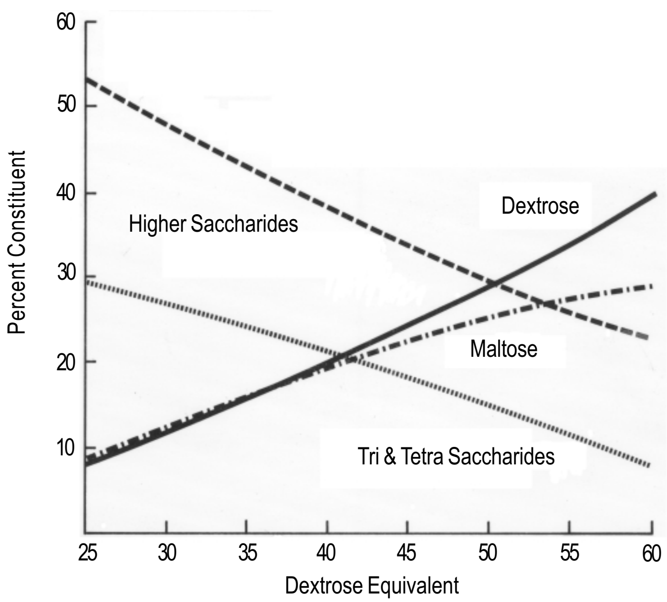
95%, crystalline). Crystallized fructose is available in several particle sizes, from powder to very large granulations. Maltodextrins are not classified in differing ranges, but are produced in a range of DE values, all below 20.

Carbohydrate Composition

In order to evaluate the functionality of individual syrups, the actual carbohydrate composition is most useful. Such information is best obtained by high performance liquid chromatographic (HPLC) analysis. Typical carbohydrate compositions of major commercially available corn syrups are shown in Table I.

Several generalizations concerning the composition of various syrups can be made. 20-38 DE (Type I) corn syrups and maltodextrins contain relatively small concentrations of low molecular weight saccharides such as dextrose, maltose and maltotriose. 58-73 DE (Type III) and 73+ DE (Type IV) corn syrups contain relatively small concentrations of the higher molecular weight oligosaccharides above maltoheptaose. 38-58 DE (Type II) syrups have mixed compositions depending on the hydrolysis processes used and the extent of conversion. Acid and acid-enzyme processes will produce products of different saccharide composition, and

Figure 5
Acid Hydrolyzed Corn Syrup Analysis



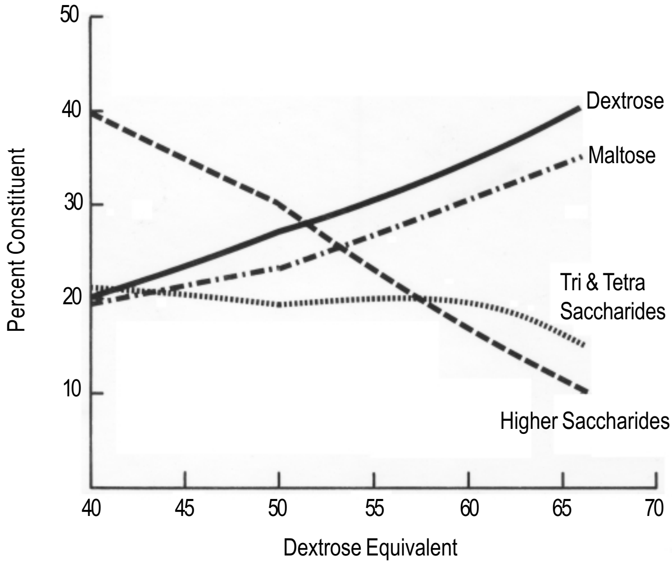


Figure 6
Acid-Enzyme Hydrolyzed Corn Syrup Analysis

are depicted graphically in Figure 5 and Figure 6. In these graphs, composition is plotted against DE so that the saccharide distribution can be read from the chart.

Other than describing the syrup by DE alone, it is frequently useful to state the composition in terms of DE and one or more of the saccharide fractions. A good example of this is 43 DE high maltose type syrup made by an acid-enzyme process. In this case, a partially acid-converted corn syrup is treated with β-amylase to produce syrup having a greater maltose concentration with a minimal amount of dextrose. The regular 43 DE (Type II) acid-converted syrup contains about 19 percent dextrose and 14 percent maltose. A 43 DE (Type II) high maltose syrup may contain about 9 percent dextrose and 43 percent maltose.

Solids Content

In addition to the carbohydrate composition, corn syrups are also characterized according to solids content. In the past, commercial corn syrups were customarily sold on a Baumé (Bé) basis, an indirect measure of the dry substance content calculated from direct measurement of specific gravity. Though still sold on this basis, analytical determinations of solids content are today made largely by direct measurement of refractive index (RI). (Abbreviated tables of refractive index/

dry substance relationships for commercial products are provided on pages 32-33.) The solids content of the more recently developed high fructose corn syrups is measured by refractive index and stated as dry substance, without reference to Baumé.

A computer program called *RI-DS*, available from Corn Refiners Association, Inc., will generate detailed tables of dry substance, refractive index, commercial Baumé, specific gravity, pounds per gallon and dry substance per gallon for corn sweeteners of known saccharide composition.

Most corn syrups are available in the range of about 77 to 85 percent dry substance. HFCS-42 (42 percent fructose) and high dextrose syrups are usually supplied at about 71 percent dry substance. HFCS-55 (55 percent fructose) and liquid fructose are supplied at a 77 percent dry substance.

Sweetness

All corn sweeteners have a clean, pleasant, sweet taste. The sweetness of corn syrups is dependent upon the concentration of sweetener and the combination of saccharides.

The effect of increasing concentration is evident when dextrose solutions are compared with sucrose solutions. A 2 percent water solution of dextrose is about two-thirds as sweet as a sucrose solution of equivalent concentration. As the concentration is increased, the difference in sweetness becomes less apparent.

Corn syrups also impart greater sweetness at higher concentrations. On a relative scale of sweetness, fructose is sweeter than glucose, which in turn is sweeter than maltose, and maltose is sweeter than higher saccharides. Since the mono- and di-saccharides also have a higher reducing power (DE), the DE value of corn syrups provides an indicator of relative sweetness differences among the four major types. High fructose corn syrups are similar to sucrose in sweetness when compared on a dry substance basis, while crystalline fructose is sweeter than sucrose.

Solutions made from crystalline fructose are nearly 1.5 times as sweet as sucrose in 2 percent solutions. As concentration increases, the sweetness of fructose relative to sucrose declines and becomes relatively constant at 1.2 times the sweetness of sucrose at concentrations of

10 percent and above.

When corn syrup, HFCS, dextrose or fructose is used in combination with sucrose, the resulting sweetness is usually greater than expected. For example, when tested at 45 percent solids, a mixture of 25 percent 42 DE corn syrup and 75 percent sucrose is considered as sweet as a sucrose solution of 45 percent solids. Hence, when corn sweeteners are used with sucrose in products having a relatively high total sweetener concentration, no apparent loss of sweetness results.

Sweetness is influenced by temperature, acids, salts and flavoring materials as well as other factors. It is difficult, therefore, to state quantitatively the relative sweetness of syrups and sugars in food formulations. Each formulated product needs to be considered individually.

Corn sweeteners are thoroughly compatible with other carbohydrate sweeteners and with food flavors. They are widely used in blends with other sweeteners. In canned fruits, a liquid packing medium containing HFCS and a 63 DE corn syrup achieves optimum sweetness while providing superior gloss and mouthfeel. The sweet taste of corn sweeteners, especially fructose-containing syrups and crystalline fructose, is perceived more quickly than sucrose. These products provide a "non-masking" source of sweetness that allows other food flavors to be perceived more intensely than similar products sweetened with sucrose.

Function and sweetness often vary in a parallel way. Manufacturers of ice cream find that body and texture are both improved, for example, through the use of corn sweeteners, and that a smoother product, with less "meltdown," and more resistance to "heat shock" results. In sherbets and ices, these sweeteners provide optimal sweetness and also tend to eliminate crystallization and promote smoothness.

Physical Properties

The physical properties of corn syrups, high fructose corn syrups, dextrose and fructose are particularly important in describing their functional capabilities in food and beverage products. In the many examples listed in Table II, the indicated use frequently reflects the functional characteristic of the end product to which the corn sweetener contributes.

Solubility

Solubility is one of these properties. All corn sweeteners are readily soluble in water. Corn syrups, for example, are aqueous solutions of starch conversion products containing about 80 percent dissolved solids at room temperature.

Dextrose, another example, has a negative heat of solution; that is, it exhibits a cooling effect when dissolved in water. This property is useful to bakers since it helps to control fermentation rates in yeast raised products.

Anhydrous dextrose melts at 144° C, while dextrose hydrate melts at 82° C and readily liquefies in a boiling water bath. Crystalline fructose will melt between 102° C and 105° C. Dried corn syrups (corn syrup solids) gradually soften and dissolve in their own moisture (deliquesce) when heated.

Hygroscopicity

Corn sweeteners are hygroscopic—that is, they readily absorb moisture—to varying degrees. The extent of hygroscopicity increases as the DE increases, since hydration is related chiefly to the monomer content. Corn syrups and dextrose are employed as moisture conditioners, food plasticizers, crystallization inhibitors and stabilizers. Fructose serves as a humectant in low or intermediate moisture foods.

Textural Characteristics

The presence of higher saccharides gives corn syrups their cohesive and adhesive properties. They contribute to the body and fullness of a product. The higher saccharides also contribute a chewy textural characteristic to various types of confections as well as to chewing gum.

Blends of nutritive sweeteners offer unusual flexibility to formulators in controlling crystallization of certain sugars, thus widening the temperature range of their utility. Moreover, the moisture holding capacity of some sugars contributes to the non-drip character of products such as hard candies and lollipops.

All of the corn sweeteners, particularly the corn syrups, control the crystallization of other sugars and increase their solubility. This property is most advantageous in products such as ice cream, frozen desserts, jams, jellies and preserves.

Corn sweeteners contribute substantially to the attractiveness of many foods. They are widely used in combination with sucrose by the fruit canning industry. The glossy appearance and syrup drainage control of fruits canned with cover syrups containing a corn sweetener is particularly pleasing to the consumer. Corn syrups also improve the gloss and clarity of hard candies, jams and jellies.

Different nutritive sweeteners affect water availability or "mobility" differently. In general, increasing the monosaccharide content will increase the starch pasting temperature, peak viscosity and gel strength. Monosaccharides such as fructose and dextrose are more effective in increasing peak viscosities than are disaccharides such as sucrose and maltose. Compared to starch/sweetener systems containing sucrose or dextrose, systems containing pure fructose demonstrate lower starch gelatinization temperatures and increased final viscosities.

Molecular Properties

Dextrose and fructose are monosaccharides of molecular weight 180—half that of the disaccharide, sucrose. They have a relatively high osmotic pressure that enhances their effectiveness in inhibiting microbial spoilage. Corn syrup of 53 DE has about the same average molecular weight as sucrose or lactose and hence, about the same osmotic properties as these sugars. Corn syrups of lower DE have higher molecular weights with correspondingly lower osmotic pressures.

The effect of corn syrups and sugars on the freezing points of solutions is important in the manufacture of ice cream and frozen desserts *(see Figure 7)*. The reduction of the freezing point of a solution is inversely proportional to the molecular weight of the dissolved solids. Generally, 20-38 DE (Type I) and 38-58 DE (Type II) syrups depress the freezing point somewhat less than an equal weight of sucrose. 58-73 DE (Type III) corn syrups have about the same effect as sucrose on the freezing point. Dextrose, 73+ DE (Type IV) corn syrups and high fructose corn syrup

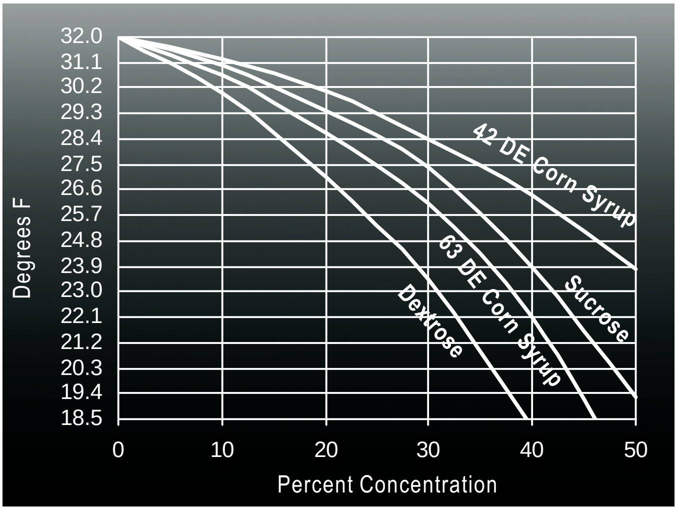
Table II: Applications of Nutritive Sweeteners Made From Corn

	Maltodextrins	Glucose Syrups	Dextrose	HFCS	Crystalline Fructose
Alcoholic Beverages, Brewing					
Ale, beer	●	●	●	●	
Brandy				●	
Cordials		●	●	●	
Liqueurs			●	●	
Wine		●	●	●	
Animal Feed					
Cat	●	●	●	●	
Cattle	●	●	●	●	
Dog	●	●	●	●	
Fish	●				
Poultry	●				
Sheep and goats	●				
Swine	●				
Baking, Snack Foods					
Baking powder			●		
Biscuits	●	●	●	●	●
Breads and rolls	●	●	●	●	
Cakes	●	●	●	●	●
Caramel color		●	●	●	
Cookies	●	●	●	●	●
Crackers	●	●	●	●	●
Doughnuts	●	●	●	●	●
Extracts and flavors	●	●	●	●	
Food coloring	●		●		
Frosting, icing, glazes	●	●	●	●	●
Pies	●	●	●	●	●
Potato chips	●		●	●	
Powdered sugar		●	●	●	
Pretzels	●	●	●	●	●
Spices	●		●		●
Yeast		●	●	●	
Beverages, Non-Alcoholic					
Carbonated	●	●	●	●	●
Fruit drinks and juices	●	●	●	●	●
Powdered mixes	●	●	●	●	●

	Maltodextrins	Glucose Syrups	Dextrose	HFCS	Crystalline Fructose
Building Materials					
Laminated	●	●			
Wallboard		●	●		
Canners & Packers					
Berries	●	●	●	●	●
Fruits	●	●	●	●	
Fruit fillings	●	●	●	●	
Fruits, candied		●	●	●	●
Fruit pectin		●	●	●	
Soups	●	●	●	●	●
Tomato sauces	●	●	●	●	●
Vegetables		●		●	
Cereals					
Cereals	●	●	●	●	●
Chemicals					
Acetic acids		●	●	●	
Antibiotics		●	●	●	
Coatings (food and drug)	●	●	●	●	●
Cosmetics					
Drugs	●	●	●	●	
Enzymes		●	●	●	
Fermentation processes	●	●	●	●	
Food acids		●	●	●	
Industrial alcohol		●	●		
Insecticides		●	●		
Intraveneous solutions			●		
Lecithin		●		●	●
Medicinal syrups	●	●	●	●	
Organic solvents	●	●	●	●	
Pharmaceuticals		●	●	●	
Shampoo		●	●	●	
Condiments					
Catsup	●	●	●	●	
Gravies	●	●	●	●	●
Mayonnaise	●	●	●	●	●
Mustard		●	●	●	

	Maltodextrins	Glucose Syrups	Dextrose	HFCS	Crystalline Fructose
Oriental sauces	●	●	●	●	●
Pickles, pickle products	●	●	●	●	
Relishes	●	●	●	●	●
Salad dressings	●	●	●	●	●
Sauce mixes	●	●	●	●	●
Vinegar		●	●	●	
Worcestershire sauce		●	●	●	
Confectionery					
Chewing gum	●	●	●	●	●
Chocolates	●	●	●	●	●
Confectionery	●	●	●	●	●
Licorice	●	●	●	●	●
Marshmallows	●	●	●	●	●
Nougats	●	●	●	●	●
Fats & Oils					
Margarine	●				
Pan coatings		●	●		
Formulated Dairy Products					
Cheese spreads and foods	●	●		●	●
Coffee whitener	●	●	●	●	
Condensed milk	●	●	●		
Frozen cream	●	●			
Ice Cream & Frozen Desserts					
Frozen puddings or custards	●	●	●	●	●
Ice cream or milk	●	●	●	●	●
Powdered mixes	●	●	●	●	●
Sherberts, water ices	●	●	●	●	●
Jams, Jellies, Preserves					
Fruit butters	●	●	●	●	●
Jams	●	●	●	●	●
Jellies	●	●	●	●	●
Marmalade	●	●	●	●	●
Preserves	●	●	●	●	●
Meat Products					
Bacon		●	●	●	
Bologna	●	●	●	●	
Breakfast meats	●	●	●	●	
Chicken products	●	●	●	●	
Dried meats		●	●	●	
Fish, seafood		●	●	●	
Hams		●	●	●	
Hot dogs		●	●	●	
Mincemeat	●	●	●	●	
Sausage		●	●	●	
Surimi					●
Miscellaneous Foods					
Baby foods	●	●	●	●	●
Dietetic preparations	●	●	●	●	●
Invalid feedings	●	●	●	●	●
Peanut butter	●	●	●	●	●
Precooked frozen meals	●	●	●	●	●
Rice and coffee polish	●	●	●		
Mixes, Prepared					
Cake mixes	●	●	●	●	●
Cookie, brownie mixes	●	●	●	●	●
Dessert mixes	●	●	●	●	●
Dried foods	●	●	●	●	●
Eggs, frozen or dried	●	●	●	●	
Frosting, icing mixes	●	●	●	●	●
Gelatin mixes	●	●	●	●	●
Gravy mixes	●	●	●	●	●
Instant breakfast foods	●	●	●	●	●
Instant tea	●	●	●	●	●
Pancake, waffle mixes	●	●	●	●	●
Quickbread mixes	●	●	●	●	●
Seasoning mixes	●	●	●	●	●
Soups, dried	●	●	●	●	●
Syrups & Sweeteeners					
Chocolate, cocoa	●	●	●	●	●
Dessert toppings	●	●	●	●	●
Fruit and table	●	●	●	●	●
Low calorie sweeteners	●	●	●	●	●
Soda fountain	●	●	●	●	●

Figure 7
Freezing-Point Relations of Sweetening Solutions



contain substantial proportions of monosaccharide and lower the freezing point to a greater extent.

Both corn syrup and dextrose are also used in the manufacture of ice cream to control sweetness and improve body and texture.

Viscosity

Viscosity, one of the most important physical properties of corn syrup, is dependent on density, DE and temperature. Viscosity decreases as DE and temperature are raised, but increases with higher density. For example, a 43 DE, 43 Bé acid-converted corn syrup has a viscosity of about 12,500 centipoises at 100° F, but only about 1,700 centipoises at 140° F. The effect of DE on viscosity is illustrated by the difference between the same syrup at 100° F (12,500 centipoises) and a 53 DE acid-converted corn syrup with the same density that shows a viscosity of only about 7,000 centipoises. The method of conversion also affects viscosity: at identical DE values, acid-converted syrups are more viscous than acid-enzyme syrups, which are thicker yet than syrups produced by enzyme-enzyme conversion.

HFCS-42 at 71 percent solids (its commercial concentration) exhibits viscosity characteristics as follows: at 60° F, 380 centipoises; at 80° F, 152 centipoises; and at 110° F, 55 centipoises. HFCS-55 at its commercial solids level of 77 percent exhibits viscosity characteristics as follows: at 60° F, 1,800 centipoises; at 80° F, 600 centipoises; and at 110° F, 120 centipoises.

Liquid fructose, when supplied at 77 percent solids, exhibits viscosity characteristics as follows: at 40° F, 6000 centipoises; at 60° F, 1700 centipoises; at 70° F, 950 centipoises; at 80° F, 530 centipoises; at 90° F, 360 centipoises; at 100° F, 240 centipoises; and at 140° F, 55 centipoises.

Chemical Properties

Fermentability

Fermentability is an important property of corn syrups and dextrose, particularly in the baking and brewing industries. The lower molecular weight sugars—primarily mono- and di- saccharides, glucose, fructose and maltose—are readily fermentable by yeast. The total fermentability of corn syrups is roughly proportional to their mono-, di- and trisaccharide content; the higher the DE, the higher the fermentability.

Reducing Characteristics

Dextrose and fructose, through their respective aldehyde and ketone reducing groups, have the ability to combine with various nitrogen compounds at elevated temperatures to produce desirable "browning" reaction products, many of which exhibit characteristic food flavors (the Maillard reaction). This property makes corn sweeteners particularly useful in the manufacture of caramel color, in the promotion of crust color in baking and production of caramel flavor.

The individual component sugars of corn sweeteners are technically termed "reducing" sugars. This "reducing" property aids in the inhibition of oxidative degra-

Table III
Dextrose Equivalents of D-glucose and its Polymers*

	Theoretical	Observed
Monosaccharide	100.00	100.00
Disaccharide	52.6	58.0
Trisaccharide	35.7	39.5
Tetrasaccharide	27.0	29.8
Pentasaccharide	21.7	24.2
Hexasaccharide	18.2	20.8

* Determined by Corn Refiners Association Analytical Method E-26

Table IV Refractive Index—Dry Substance Tables for Typical Corn Syrups

%DS	RI 20°C	RI 45°C	BÉ,COMM 140/60°F +1.0	SP G AIR/AIR 100/60°F	TOTAL LBS/GAL 100°F	DRY SUB LBS/GAL 100°F
			28 DE			
76.0	1.48881	1.48372	40.98	1.3929	11.60	8.82
77.0	1.49154	1.48643	41.49	1.3996	11.66	8.98
78.0	1.49429	1.48917	42.00	1.4064	11.72	9.14
79.0	1.49707	1.49192	42.51	1.4132	11.77	9.30
80.0	1.49986	1.49470	43.01	1.4201	11.83	9.46
			36 DE			
78.4	1.49377	1.48866	42.01	1.4065	11.72	9.19
79.4	1.49652	1.49139	42.52	1.4133	11.77	9.35
80.4	1.49929	1.49414	43.02	1.4202	11.83	9.51
81.4	1.50208	1.49692	43.53	1.4271	11.89	9.68
82.4	1.50489	1.49971	44.03	1.4340	11.95	9.84
			34 HM (HIGH MALTOSE)			
78.6	1.49330	1.48818	41.99	1.4061	11.71	9.21
79.6	1.49603	1.49089	42.49	1.4129	11.77	9.37
80.6	1.49878	1.49363	42.99	1.4197	11.83	9.53
81.6	1.50155	1.49638	43.49	1.4265	11.88	9.70
82.6	1.50434	1.49916	43.99	1.4334	11.94	9.86
			43 HM (HIGH MALTOSE)			
78.9	1.49337	1.48825	42.00	1.4063	11.71	9.24
79.9	1.49609	1.49096	42.51	1.4131	11.77	9.41
80.9	1.49883	1.49368	43.01	1.4199	11.83	9.57
81.9	1.50159	1.49642	43.51	1.4268	11.89	9.73
82.9	1.50437	1.49919	44.01	1.4336	11.94	9.90
			43 DE			
78.7	1.49330	1.48820	42.01	1.4065	11.72	9.22
79.7	1.49603	1.49091	42.52	1.4133	11.77	9.38
80.7	1.49878	1.49364	43.02	1.4201	11.83	9.55
81.7	1.50155	1.49639	43.52	1.4269	11.89	9.71
82.7	1.50434	1.49917	44.02	1.4338	11.94	9.88
			43 DE (ION EXCHANGED)			
78.8	1.49351	1.48840	41.99	1.4063	11.71	9.23
79.8	1.49624	1.49111	42.50	1.4130	11.77	9.39
80.8	1.49899	1.49385	43.00	1.4198	11.83	9.56
81.8	1.50175	1.49660	43.50	1.4266	11.88	9.72
82.8	1.50454	1.49937	44.00	1.4335	11.94	9.89
			53 DE			
80.5	1.49618	1.49107	42.64	1.4150	11.79	9.49
81.5	1.49890	1.49377	43.14	1.4217	11.84	9.65
82.5	1.50164	1.49650	43.64	1.4285	11.90	9.82
83.5	1.50440	1.49924	44.13	1.4354	11.96	9.98
84.5	1.50718	1.50201	44.63	1.4423	12.01	10.15
			63 DE			
81.0	1.49555	1.49045	42.53	1.4133	11.77	9.54
82.0	1.49823	1.49312	43.02	1.4200	11.83	9.70
83.0	1.50093	1.49581	43.52	1.4268	11.89	9.87
84.0	1.50366	1.49852	44.01	1.4336	11.94	10.03
85.0	1.50640	1.50125	44.50	1.4405	12.00	10.20

%DS	RI 20°C	RI 45°C	BÉ,COMM 140/60°F +1.0	SP G AIR/AIR 100/60°F	TOTAL LBS/GAL 100°F	DRY SUB LBS/GAL 100°F
			63 DE (ION EXCHANGED)			
81.3	1.49628	1.49118	42.61	1.4144	11.78	9.58
82.3	1.49897	1.49385	43.10	1.4211	11.84	9.74
83.3	1.50168	1.49655	43.60	1.4279	11.89	9.91
84.3	1.50440	1.49926	44.09	1.4347	11.95	10.07
85.3	1.50715	1.50200	44.58	1.4415	12.01	10.24
			66 DE			
81.0	1.49486	1.48977	42.36	1.4111	11.75	9.52
82.0	1.49753	1.49243	42.86	1.4178	11.81	9.68
83.0	1.50021	1.49510	43.36	1.4246	11.87	9.85
84.0	1.50292	1.49779	43.85	1.4314	11.92	10.02
85.0	1.50565	1.50050	44.35	1.4383	11.98	10.18
			95 DE			
69.0	1.45977	1.45495	35.46	1.3237	11.03	7.61
70.0	1.46209	1.45726	35.96	1.3296	11.08	7.75
71.0	1.46443	1.45959	36.46	1.3356	11.13	7.90
72.0	1.46679	1.46193	36.96	1.3417	11.18	8.05
73.0	1.46916	1.46429	37.45	1.3477	11.23	8.20
			95 DE (ION EXCHANGED)			
69.0	1.45972	1.45491	35.40	1.3229	11.02	7.60
70.0	1.46205	1.45721	35.89	1.3288	11.07	7.75
71.0	1.46438	1.45954	36.39	1.3348	11.12	7.89
72.0	1.46674	1.46188	36.89	1.3408	11.17	8.04
73.0	1.46911	1.46423	37.38	1.3469	11.22	8.19
			HFCS 42			
69.0	1.45968	1.45425	N/A	1.3252	11.04	7.62
70.0	1.46200	1.45655	N/A	1.3311	11.09	7.76
71.0	1.46434	1.45886	N/A	1.3372	11.14	7.91
72.0	1.46669	1.46118	N/A	1.3432	11.19	8.06
73.0	1.46906	1.46352	N/A	1.3493	11.24	8.20
			HFCS 55			
75.0	1.47377	1.46799	N/A	1.3621	11.35	8.51
76.0	1.47619	1.47037	N/A	1.3683	11.40	8.66
77.0	1.47862	1.47277	N/A	1.3746	11.45	8.82
78.0	1.48107	1.47519	N/A	1.3808	11.50	8.97
79.0	1.48353	1.47763	N/A	1.3872	11.55	9.13
			LIQUID FRUCTOSE			
75.0	1.47322	1.46673	N/A	1.3639	11.36	8.52
76.0	1.47562	1.46909	N/A	1.3701	11.41	8.67
77.0	1.47803	1.47146	N/A	1.3763	11.46	8.83
78.0	1.48046	1.47385	N/A	1.3825	11.52	8.98
79.0	1.48291	1.47626	N/A	1.3888	11.57	9.14

*Refractive index is dependent on product composition, including saccharide profile and inorganic (ash) content. Actual refractive index values for individual products may vary slightly among producers. For precise dry substance determination, refer to product composition data and the computer program RI-DS, available from the Corn Refiners Association, Inc.

radation in foods. It is useful in maintaining the bright red color of tomato catsup and strawberry preserves and helps to retain the characteristic color of cured meats. This chemical reducing action of syrups and sugars is also measured and expressed by dextrose equivalence (DE). Table III shows the relative reducing power of various sugars.

The observed values represent a summation of a complex of chemical reactions. Therefore, precise conditions must be maintained in making a DE determination. DE values are not used to characterize high fructose corn syrups.

pH Values of Corn Syrups

Corn syrups are finished and stored slightly on the acid side. They are available in a pH range of about 3.5 to 5.5. Because traditional pH measurement is difficult in ion-exchanged products such as high fructose corn syrup, acidity in these products is often measured by titratable acidity or conductivity.

Additional data on corn derived sweeteners are available from the Corn Refiners Association and the members of the Association.

There are countless methods for determining the chemical and physical properties of corn sweeteners. The Corn Refiners Association, through its Quality Systems Committee, has spent many years developing and standardizing practical and effective analytical procedures for corn starch and starch-derived products. The Committee actively continues its work on standardization of analytical procedures today.

The Corn Refiners Association publishes these analytical procedures and makes them available at no charge. These methods are published in *Analytical Methods of the Member Companies*, which is available from Corn Refiners Association website at www.corn.org. By cooperation with the Association of Official Analytical Chemists, many of these methods are available through that organization's reference publications as well.

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