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Preface

Sucrose is a basic carbohydrate and has occupied a central position in human food for centuries. Sugar contributes to the pleasant taste and physical structure of many foods. This monograph is intended to provide an overview of the numerous roles of sucrose in various food and nonfood processes. *Sugar: A User's Guide to Sucrose* has been structured as a basic reference source for the fundamentals of sucrose functionality and utility.

Authors from the food industry and academia were selected on the basis of their recognized expertise in the functional roles of sucrose in the formulation and final quality of a specific food. Each author writing about a specific food has described why sucrose-based formulations are the standards against which alternative formulations or processes are judged. In addition to the fundamentals of sucrose usage in foods, other authors have communicated the role of sucrose in flavor and taste, a balanced diet, microwave cooking, and the synthesis of specialty chemicals such as detergents, pharmaceuticals, and cosmetics.

The histories of cane and beet sugar development and processing were included to show that sucrose has been an important agricultural commodity and food for centuries. Although the number of specific sugar products is more numerous in today's world, refined sucrose is essentially the same today as in past centuries. From its formation during photosynthesis through its refinement to a high-quality product, sugar is an essential ingredient in a wide range of foods and an important source of food energy.

Scientists and technologists in the food and beverage industries will be interested in the discussion of the physical and chemical properties of sucrose that impact its processing, food-specific functionality, and behavior under the influence of microwave heating and cooking, and also the analytical methods used to ensure sucrose quality. These sections will also satisfy the requirements of

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educational or apprentice programs of the food and beverage industries. Terminology common to the sugar industry and the listing of sugar industry companies, associations, and affiliates were compiled for the benefit of various trade and professional associations, production and marketing management, and food media professionals.

Sugar: A User's Guide to Sucrose is the result of the efforts of eighteen authors. The co-editors thank each author.

Sugar

A User's Guide to Sucrose

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History of Cane and Beet Sugar

Laszlo Toth, Ph.D., and A. B. Rizzuto *

History is defined as a chronological account of what has happened of significance in the life and development of a people, country, or institution; also it can be a scientific account of a system of natural phenomena. A thorough history of sugar would be very lengthy because it began millions of years ago. The creation of sugar, which the chemist calls sucrose, belongs to the infinite wisdom of nature. The sophisticated chain of reactions that first occurred millions of years ago still goes on in the majestic laboratories of Mother Nature where solar energy is captured in certain plants to form sugar. Its sweet flavor resulted from pure solar energy centuries ago as it does today, providing energy required by each living being to sustain life.

Rather than starting at the beginning, this chapter will address events related to the development of the industry that today processes and packages sugar. Statistics record that the world today manufactures and consumes over 110,000,000 tons of sugar per year. Taking into consideration that primitive domestic sugar manufacturing, mostly in South and Southeast Asia, is not included in this figure, total yearly world sugar production could be close to 125 to 130 million tons. This tremendous amount of product is an important, worldwide source of human energy.

The industrial production of sugar/sucrose is based exclusively on sugarcane and sugar beet processings. Sugarcane is a tropical plant, while the sugar beet flourishes in cooler climates. Sugarcane is grown and cane sugar is produced in tropical and subtropical countries. All these regions are inside a belt, whose northern

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borderline crosses the North American continent at southern California and South Carolina, the European continent at the southern tip of the Iberian Peninsula and Sicily, the Asian continent at the Middle East countries through Pakistan and south China, and the Pacific Ocean at the 37th parallel. In the Southern Hemisphere the borderline goes through the southern tip of Brazil, crosses the Atlantic Ocean, the African continent at Natal, the Indian Ocean, the northeastern coast of Australia, and the Pacific Ocean on the 34th parallel. In all regions outside this belt, in the northern and southern hemispheres, the sugar beet dominates.

Despite the fact that refined cane and beet sugar are physically as well as compositionally identical materials, the colorful histories of their development are very different.

In the very beginning sugar was not known in its solid form but only as a sweet syrup obtained from sugarcane. Its name originated from the Sanskrit word "Sharkara," which denotes "material in a granular form," and is the origin of the term "sugar" in modern languages—Arabic "suchar"; French "sucre"; German "zucker"; Hungarian "cukor"; Russian "sahar"; Spanish "azucar." The story of both sugars, cane and beet, is woven into historic tales of adventure and discovery. It is important in trade and commerce today as in the past. Sugar has played a fascinating role in the destinies of nations in war and peace.

Sugarcane History

The oldest source for sugar manufacturing is sugarcane. There are indications of primitive sugar manufacturing in New Guinea more than 12,000 years ago.

Sugarcane production spread southeastward to the New Hebrides and New Caledonia in about 8000 B.C. In approximately 6000 B.C., sugar manufacturing appeared in Celebes, Borneo, Java, Indochina, and India. From India, sugarcane was carried to China, where soil conditions were ideal for its growth. Chinese literature records that in about 200 B.C. the Emperor Tai-Sun sent his emissary to India to learn cane sugar manufacturing. Also, the Chinese emperor received sugarcane as a tribute from the kingdom of Funam. Most likely the sugarcane arrived in Persia, Arabia, and Egypt about the same time. In the meantime, it also found its way into Syria, Palestine, and the island of Cyprus.

The first written records in European literature dealing with cane sugar date from the era of Alexander the Great's war with India, 327 B.C. His army commanders, Nearhos and Onescritos, reported on "honey that is produced from cane, without participation of honey bees." Cane sugar's trek to numerous northeastern Pacific islands and Hawaii took place in quite recent history, mostly during the first millennium A.D.

Closer knowledge in Europe about sugar was spread during the Crusades in the eleventh to thirteenth centuries. Many people from various European nations and social levels fought in this series of campaigns. Some records show that large cane plantations belonged to various Christian orders in the region. Shipping and trade between the Mideast and Europe during this period was almost exclusively in the hands of Venetian merchants. There are indications that, besides raw sugar trade, the Venetians also invented some primitive sugar refining. There is evidence that in the middle of the fourteenth century the Venetians were manufacturing and trading "sugar loaves" with their customers.

The various Arab armies brought sugarcane with them during their conquests across the northern coast of Africa. Possibly, from there it made its way into Spain and Sicily about 700 A.D., though there are indications that some sugarcane might have been in the Mediterranean coastal lands earlier. According to some sources, the Moorish conquering army brought sugarcane plants along with their science and inventions.

Sugar was one of the first pharmaceutical ingredients used, as it still is today, to mask the bitter or unpleasant taste of medicines. Sugar was so rare that a teaspoon of it in the sixteenth century commanded the equivalent of five dollars. According to English records from the seventeenth century, one could purchase a calf for four pounds of sugar. The price was still very high in the eighteenth century.

The quest for sugar and spices ushered in the age of discovery. The Portuguese were leading explorers and colonizers. They established sugar as a crop in Madeira, the Azores, and the Cape Verde Islands. The Spanish brought cane to the Canary Islands. Slave labor in these colonies produced sugar at a lower-cost than possible in Mediterranean countries.

On his second voyage to the New World, Columbus brought cane cuttings to Hispaniola, the island we know now as the Dominican Republic and the Republic of Haiti. The first attempt to grow cane failed, but by 1509 sugar was being produced in profitable amounts.

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Sugar shaped a good deal of the history of the New World. By 1520 cane was growing in Mexico, and the Spanish explorer Cortez established the first North American sugar mill there in 1535. Cultivation soon spread to Peru, Brazil, Columbia, and Venezuela. Puerto Rico had a mill by 1548. By 1590 more than one hundred sugar mills were flourishing in Brazil alone. In 1624 Brazil fell to the Dutch, but Dutch rule lasted only until 1654, when the Portuguese took over again and expelled 20,000 Dutch. Many of them migrated to the West Indies, where they contributed their knowledge to the production of sugar.

The "sugar islands" of the West Indies brought great wealth to England and France. Queen Elizabeth displayed her wealth by putting a sugar bowl on her table and using sugar as an everyday food and seasoning. It soon appeared at court banquets. Great Britain took a commanding position in the sugar trade, and it was not long before the introduction of coffee, chocolate, and tea in the English diet tremendously increased the use of sugar. By the end of the seventeenth century, these new beverages were in general use, and by the eighteenth century the demand for sugar was so great that it became a matter of active public interest. Historic records show that large amounts of revenue for the Spanish and British crowns were derived from the great sugar plantations along the Spanish mainland and from the British islands of Jamaica, St. Kitts, and Barbados.

The Jesuits, who introduced cane cultivation to the Argentines in 1670, were the first to bring sugarcane to what is now the United States. In 1751, the first crop was planted in Louisiana with cuttings brought from Santo Domingo. The cane thrived, but no progress was made in extracting sugar. Planting on a large scale was abandoned in 1776, and the industry languished until 1791, when it was again tried, this time with success.

On the other side of the world, the island of Mauritius in the Indian Ocean started production in 1747. In 1824, cane growing was introduced in Australia.

In other places later to become part of the United States, sugarcane cultivation was slower to take hold. Sugarcane is reported to have been grown in New Smyrna, Florida, as early as 1767; however, it was not until the early 1920s that the first extensive commercial plantings were established near Canal Point east of Lake Okeechobee (7). Sugarcane was grown for home use in the Hawaiian Islands prior to 1778, but the first large-scale plantings were not started until 1825 (8). The initial plantings of sugarcane in Texas were early

in the nineteenth century. However, it was not until 1913, in the Rio Grande Valley, that the Texas sugarcane industry reached a high of five sugar mills in operation (9). This peak in the Texas sugar industry was short-lived due to economic and political conditions which caused the last mill to close in 1921. The present Texas sugar industry was established in the Rio Grande Valley when a group of one hundred farmers formed a sugarcane cooperative in 1970.

Sugar Beet History

Sugar beet cultivation and the extraction of sugar from the plant is a younger technological development than that of sugarcane. Since ancient times, a white-colored beet called the "Beta Maritima," has been grown in Mediterranean countries, but it was not until 1590 that anyone recorded its sweet properties. That year, Oliver De Serres prepared a syrup from beets and noted that the "juice yielded on boiling is similar to sugar syrup." More than 150 years later, in 1747, Andreas Marggraf, a member of the Berlin Academy of Sciences, became interested in the "sweet root's" properties. During his laboratory tests he succeeded in extracting sugar from thin slices of beets, using alcohol, and in crystallizing it. No practical use was made of this discovery until 1798, when F. C. Achard, a German pharmacist who had been a student of Marggraf, separated ten pounds of sugar in a small pilot plant. He presented this refined beet sugar and his written report to the King of Prussia. The report described methods used and the economic importance of developing a new industry based on extracting and crystallizing sugar from sweet roots of "Beta Maritima." This resulted in the establishment of the first beet sugar factory on the estates of Kunern in Silesia. The first processing started in April 1802, and with relatively primitive technology coupled with low beet sugar content, the factory was able to produce about three pounds of sugar for each hundred pounds of beet. Despite the very low efficiencies and high sugar losses, this factory and other early beet sugar factories were successful due to the high sugar prices prevailing at that time.

The real push for the development of a large-scale beet sugar industry came with the Napoleonic Wars and the continental blockade in 1806. The blockade prevented any merchandise from England or its colonies from entering the European continent. Since the only sugar available to most European countries at that time was shipped overseas from cane plantations in their tropical colonies, a severe sugar shortage occurred. To overcome this shortage,

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Napoleon's French government offered a bounty on beet sugar, established six special beet sugar schools for select students, set aside large tracts of land, and compelled the peasant farmers to plant sugar beets. These various governmental acts, together with the high price of sugar, resulted in rapid development of the new technology. In 1813, only eleven years after the start-up of the first beet sugar factory, and only seven years after the continental blockade, 334 beet sugar mills were operational in France, Germany, and Austria-Hungary. The factories of the time were of very small capacities, barely processing one hundred tons of beets per day, with primitive equipment and poor quality beets that usually contained no more than 5 to 6 percent sugar.

After the Napoleonic Wars, the cane sugar supply started its free flow again, causing a serious but not long-lasting slowdown in the young beet sugar industry. Progress had been made in developing better-quality beets. The process of beet selection had already been started by Achard, but in 1821 Pelouze, through research in plant breeding, was able to produce a dramatic increase in the sugar content of beets. This improvement, together with high sugar prices, allowed the industry to progress rapidly again, so that by 1836 there were 436 beet sugar factories in operation.

The young beet sugar industry received a new shot in the arm with the revolt of slave labor on the sugarcane plantations of Santo Domingo. The interruptions in overseas cane sugar production caused a further strain on the sugar supply, and prices increased consequently, encouraging further beet sugar development.

In the second half of the nineteenth century, a series of improvements, inventions, and new ideas caused radical changes in beet sugar technology and led to more efficient and economical processing. These processes are still in use today. In 1840, lime-carbon dioxide juice purification was introduced. In 1843, the multiple-effect evaporator, developed for the cane sugar industry, was put in service. In 1844, centrifugal separation of crystals from *massecuite*, a dense syrup containing sugar crystals, was begun. In 1863, the Roberts diffusion battery was employed to extract sugar from beets, and by 1870, the vacuum pan and efficient crystallization technology were coming into general use. Patented in 1883, the Steffen Process increased sugar recoveries. In 1884, the idea of crystallization dynamics was proposed and resolved by G. Z. Wulff. All these developments created a strong and vital industry. By 1914 world production of beet sugar was 9,051,767 tons, compared with cane sugar production of 11,523,158 tons.

The development of the beet sugar industry in the United States paralleled that of Europe. Many failures were experienced during the early years of the industry. In 1838, the first factory in the United States was erected in Northampton, Massachusetts, by David Lee Child. It was a failure and ceased to operate after 1840. Between 1838 and 1870 there were several unsuccessful attempts to erect and run a beet sugar factory: White Pigeon, Michigan, in 1848; Salt Lake City, Utah, built by the Mormons in 1853; a factory built by the Gennett brothers in Chatsworth, Illinois, in 1866; a factory built by Otto and Bonesteel in Fond du Lac, Wisconsin, in 1868; and a beet sugar plant built by E. H. Dyer in Alvarado, California, in 1870. In 1879, E. H. Dyer, after four complete financial failures and reorganizations, succeeded in putting the Alvarado plant on a paying basis. In 1888, Claus Spreckels started a successful plant in Watsonville, California.

From that time on, the growth of beet sugar in the United States has been fairly constant. In 1915, seventy-nine beet sugar factories were in operation, and by 1919 the number had grown to one hundred.

The Sugar Industry Today

The American cane and beet sugar industries of 1990 reflect the dramatic changes caused by the development in the early 1970s of isomerized corn syrups and nonnutritive, artificial sweeteners. Though cane and beet sugars remain the standard measure of quality, taste, and functionality, corn syrups and artificial sweeteners have each established themselves as substitutes for sugar in segments of the sweetener market. Figure 1-1 shows U.S. per capita sweetener consumption from 1980 to 1989.

Despite competition from new products, the American cane and beet sugar industry remains vital, as the latest statistical data show. Present U.S. sugar consumption is approximately 8.35 million tons per year, and according to forecasts, it will maintain the same general level for the next few years. Cane sugar products are processed in twelve refineries with production of approximately five million tons per year of sugar. Thirty-eight sugar beet factories produce about 3.5 million tons per year. In order to supply the cane sugar refineries, about eight hundred thousand acres of cane are harvested in Florida, Louisiana, Texas, and Hawaii and milled in forty-two raw sugar plants. An additional one million tons of raw sugar are imported each year. Beets are harvested on 1.3 million

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acres of land and processed in thirty-eight sugar factories in thirteen states. Figures 1-2 and 1-3 compare U.S. and world sugar production yields of sugarcane and sugar beet.

The contemporary sugar industry represents a vital part of the U.S. economy and employs a large number of people in such activities as the growing and harvesting of beet and cane sugar, cane refining, raw sugar milling, cane and beet sugar processing, research, sales, and service. In addition, an enormous number of suppliers of raw materials, chemicals, machines, and parts amount to several hundred additional people for each factory. Most important are the countless industrial users of sugar that depend on a steady, reliable source and the grocery stores that supply the consuming public. In the U.S.A. alone, the sweetener industry directly and indirectly generates \$18.5 billion per year in wages and revenues and give jobs to 361,000 employees in forty-two states.

So, sugar processing has come a long way in the 12,000 years since its beginnings in New Guinea.

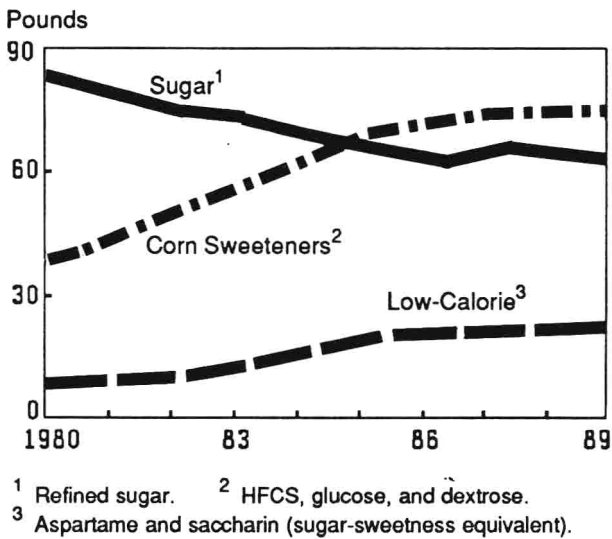


Figure 1-1. U.S. per capita sweetener consumption, 1980-89. (Source: U.S. Department of Agriculture, *Sugar and Sweetener Situation and Outlook Report*, Dec. 1989.)

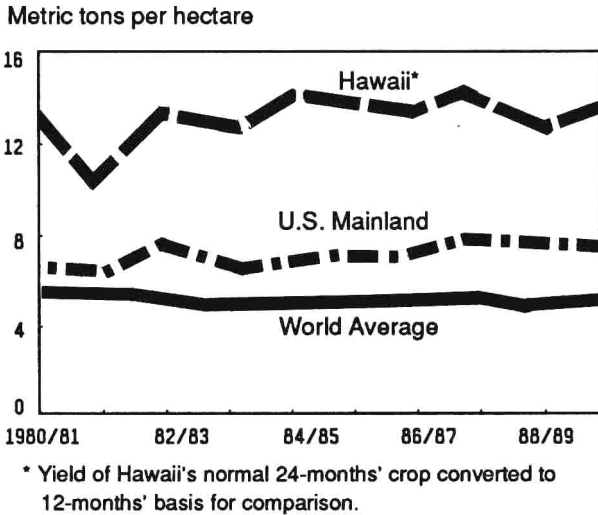


Figure 1-2. U.S. and world cane sugar yields, 1980-89. (Source: U.S. Department of Agriculture, *Sugar and Sweetener Situation and Outlook Report*, Dec. 1989.)

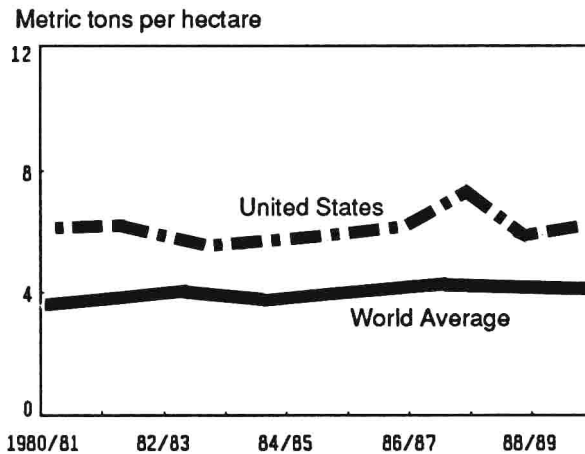


Figure 1-3. U.S. and world beet sugar yields, 1980-89. (Source: U.S. Department of Agriculture, *Sugar and Sweetener Situation and Outlook Report*, Dec. 1989.)