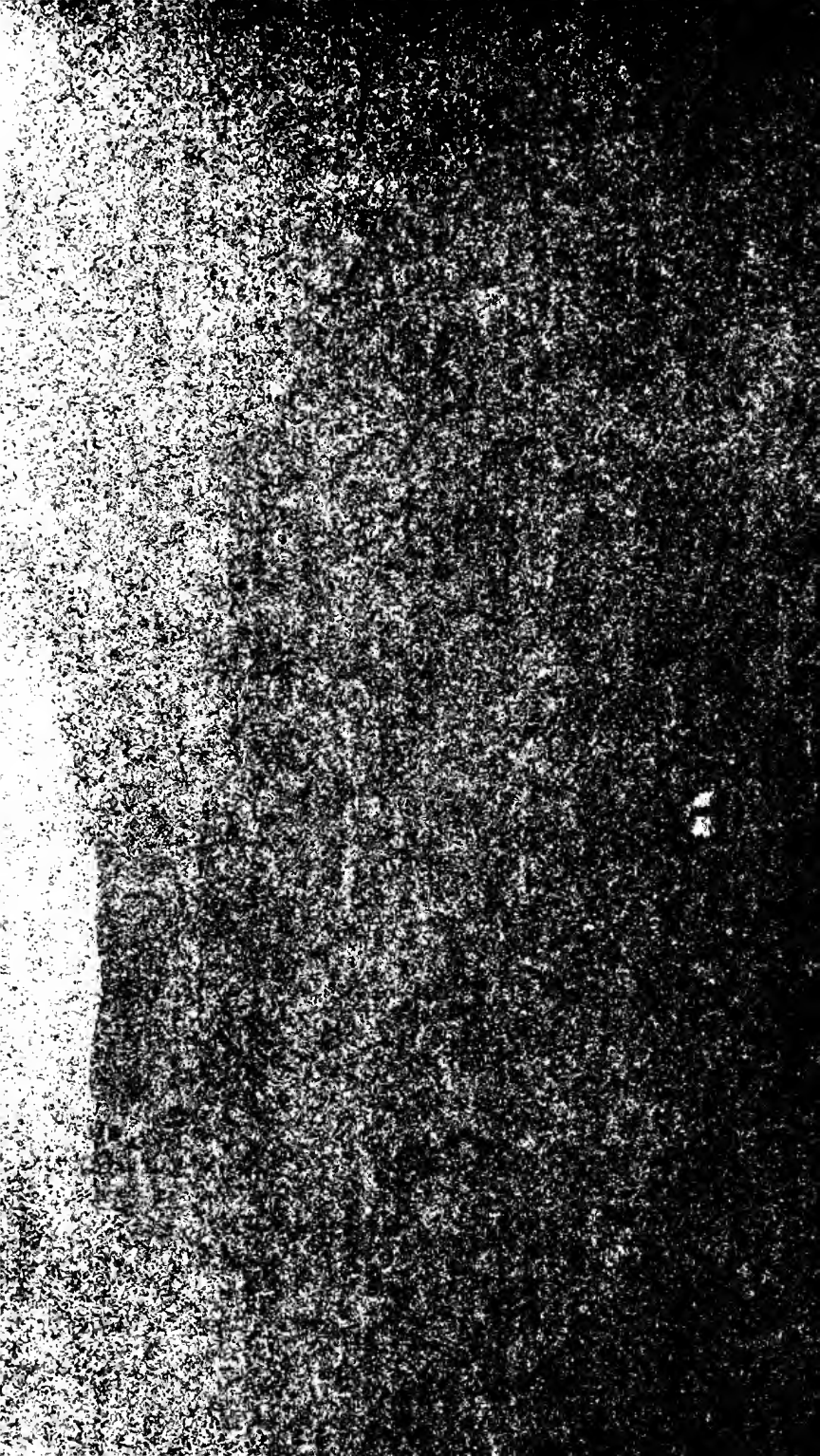


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SUGAR AND SUGAR-MAKING

BY

JAMES B. McNAIR

ASSISTANT CURATOR OF ECONOMIC BOTANY



BOTANY

LEAFLET 13

FIELD MUSEUM OF NATURAL HISTORY

CHICAGO

1927

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LIST OF BOTANICAL LEAFLETS ISSUED TO DATE

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D. C. DAVIES, DIRECTOR

FIELD MUSEUM OF NATURAL HISTORY
CHICAGO, U. S. A.



Courtesy of the United Fruit Co.

SIXTEEN SUGAR CANES FROM ONE SEED IN CUBA.

FIELD MUSEUM OF NATURAL HISTORY

DEPARTMENT OF BOTANY

CHICAGO, 1927

LEAFLET

NUMBER 13

Sugar and Sugar-Making

Sugar is manufactured by plants for their own use. It is formed in their green parts from carbon dioxide of the air and the water of the sap. Under the influence of sunlight filtered by the green coloring matter (chlorophyll) of the plant, the gas and water combine to form formaldehyde which is later converted into glucose and other sugars.

Sugar is soluble in the plant sap and is carried in the sap to various parts of the plant to be transformed where needed into other substances such as fiber. Some plants store sugar for future use, e. g., for the growth and seed-production of the following year, as is the case with the sugar beet.

For storage, particles of sugar may unite with each other to form larger, less soluble bodies such as starch due to the union of glucose with glucose in potatoes, the starchlike substance inulin from the sugar levulose with levulose in dahlia tubers, cherry tree gum from the sugar arabinose with arabinose in cherry trees, and gum arabic from the sugar galactose, arabinose, and arabinon in acacia trees.

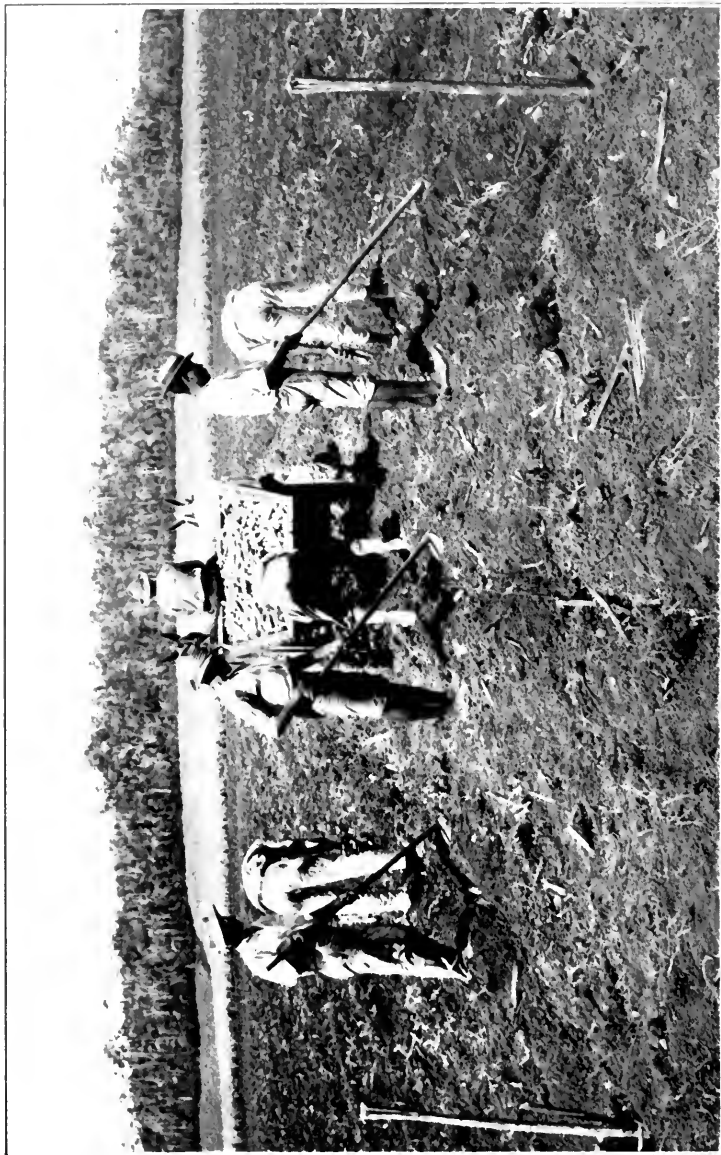
Sugar may also join with other substances in plants as when glucose unites with gallic acid to form tannin in the oaks and sumacs, rhamnose with fisetin to form the dye stuff fustic in the smoke-wood tree (*Rhus Cotinus*), and mannose with cellulose to form

“vegetable ivory” in the kernel of the ivory palm (*Phytelephas macrocarpa*). Sometimes these compounds are poisonous as in the cases of arbutin and amygdalin. Arbutin is found in the trailing arbutus and bearberry, while amygdalin is found in the seeds of the bitter almond, apricot, and peach.

Besides its use as food for the plant, sugar manufactured by plants also serves a useful purpose in the nectar of flowers by attracting insects for pollination and in fruits by making these attractive to animals that aid in seed dissemination. Nectar contains for the most part cane sugar, glucose, and levulose, and is taken by bees to form honey. Some flowers contain sufficient nectar to be attractive to man as a source of sugar. Among these are those of the Madhuca tree (*Madhuca latifolia*), the Honey Flower (*Melianthus major*), and the Boer Honey Pots (*Protea mellifera* and *Protea cynaroides*). W. Ferguson says that in the time of Manu, about 4,000 years ago, the Hindus knew how to make sugar from the flowers of the Madhuca tree. The natives of Cape Colony collect the Honey Flowers for the large quantity of sugar they contain, and the Boers of South Africa make use of the Honey Pot flowers for the same purpose.

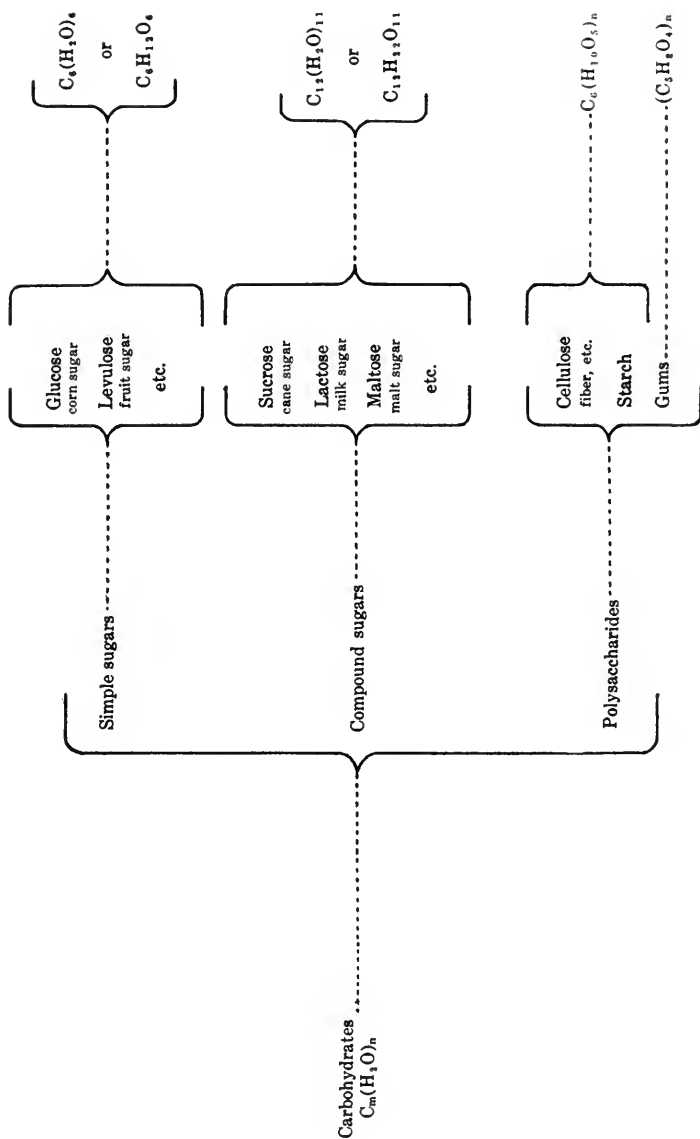
Many different sugars occur in nature in plants and animals. Other sugars not yet found in nature are produced synthetically in the laboratory. The general term “sugar” applies to a large number of substances composed of three elements, carbon, hydrogen, and oxygen combined in certain proportions. Sugars which possess distinct chemical and physical properties are distinguished by special names, e. g., sucrose.

The sugars belong to a much larger group of substances called carbohydrates, most of which conform to the general formula $C_m (H_2O)_n$, where m and n stand for various multiples. See outline on page 4. The



Courtesy of the United Fruit Co.

PLANTING SHORT PIECES OF CANE IN CUBA.



other plant substances of this group, cellulose, starch, and gum, are more complex but may be decomposed or broken down into various sugars.

Commercial sugars are named after the particular plants from which they are extracted, for instance, cane, beet, maple, sorghum, palm. The chief constituent of all these is a single substance—sucrose or saccharose. Corn and grape sugar on the contrary consist of another chemical substance—glucose.

All sugars are not of equal sweetness. Corn sugar (glucose) is only three-fifths as sweet as cane sugar, while levulose is about equal to cane sugar in sweetness.

CANE SUGAR

The sugar cane (*Saccharum officinale*) belongs to the grass family (*Gramineae*) which includes wheat, oats, corn¹ (maize), sorghum, etc.; but the sugar cane towers above most of them, sometimes attaining a height of twenty feet. Its native country is Southern or Southeastern Asia. Being a plant of the moist tropics and subtropics, it grows successfully only where the average temperature does not fall much below 80° Fahrenheit nor the rain below sixty inches a year.

History.—Various classical writers of the first century noticed the sweet sap of the Indian honey-bearing reed or its granulated saltlike product. This product was imported to Europe from India and from Arabia and Opone (these being entrepots of Indian trade) under the name of saccharum (σακχαρι from Sanskrit *sarkara*, gravel, sugar), for medical use.

Before the Middle Ages Europeans had no clear idea of the origin of cane sugar. It was confounded

¹The Aztecs in Mexico made use of the corn plant for sugar in the same manner as sugar cane is used now.

with manna or was thought to exude from the stem of a plant, on which it dried into a kind of gum. The art of boiling sugar was known in Gangetic India, from which it was carried to China in the first half of the seventh century; but sugar refining cannot have been known then, for the Chinese learned the use of ashes for this purpose only in the Mongol period (600 A. D.), from Egyptian visitors. The cultivation of the cane in the West spread from Khuzistan in Persia. At Gunde-Shapur in this region "sugar was prepared with art" about the time of the Arab conquest, and its manufacture on a large scale was carried on at Shuster, Sus, and Askar-Mokram throughout the Middle Ages. It has been plausibly conjectured that the art of sugar refining, which the farther East learned from the Arabs, was developed by the famous physicians of this region, in whose pharmacopoeia sugar had an important place. Under the Arabs, the growth and manufacture of the cane spread far and wide, from India to Sus in Morocco, and was also introduced in Sicily and Andalusia.

In the age of discovery, the Portuguese and Spaniards became the great disseminators of the cultivation of sugar; the cane was planted in Madeira in 1420; it was carried to San Domingo in 1494; and it spread over and occupied portions of the West Indies and South America early in the sixteenth century. Within the first twenty years of the sixteenth century the sugar trade of San Domingo expanded with great rapidity, and it was from the dues levied on the imports brought thence to Spain that Charles V obtained funds for his palace-building at Madrid and Toledo.

In the Middle Ages, Venice was the great European center of the sugar trade, and toward the end of the fifteenth century a Venetian citizen received a reward of 100,000 crowns for the invention of the art of mak-



Courtesy of the International Harvester Co.

A PRIMITIVE SUGAR CANE MILL WORKED BY BUFFALOES IN JAVA.

ing loaf sugar. One of the earliest references to sugar in Great Britain is that of 100,000 pounds of sugar being shipped to London in 1319 by Tomasso Lore-dano, merchant of Venice, to be exchanged for wool. In the same year there appears in the accounts of the Chamberlain of Scotland a payment at the rate of 1s 9½*d* per pound for sugar. Throughout Europe it continued to be a costly luxury and article of medicine only, till the increasing use of tea and coffee in the eighteenth century brought it into the list of principal food staples. The increase in the consumption is exemplified by the fact that, while in 1700 the amount used in Great Britain was 10,000 tons, in 1800 it had risen to 150,000 tons, and in 1885 the total quantity used was almost 1,100,000 tons. In 1924-25 the United States produced 88,483 of a world-production of 17,649,000 short tons.

Sugar cane was introduced into Louisiana from San Domingo by the Jesuits in 1751. Dubeuil built the first cane-mill, and his efforts at manufacture failed. The first refined sugar was made by Antonio Mendez in 1792, but the first refined sugar on a commercial scale was made in 1794 by Etienne de Boré. The plantations of these two planters now form part of the city of New Orleans.

The manufacture of sugar was very crude up to 1700. Inefficient mills operated by wind, water, or oxen were used for extraction with lime, clay, and ashes as purifying agents; the evaporation was effected in open copper or iron pans placed directly over the fire, and the refining consisted in melting, boiling, and recrystallizing. These crude methods still exist in some countries, especially in districts where cane is grown for making syrup and very crude sugar.

Extraction.—There are in practice two methods of extracting the sugar from cane, namely, milling

and diffusion. The older and more generally used is milling, the diffusion being confined almost entirely to manufacture of sugar from beets. A mill may consist of two or three rollers, usually placed horizontally and varying in length from eighteen to seventy-two inches, and in diameter from twelve to thirty-two inches. If the mill is to be operated by oxen or by horses the rollers are set in an upright position. The most primitive mill was the wooden roller. This has been used in a small way in some of the southern states since the Civil War, but there is at this time, perhaps, not one in existence in this country. In most large factories there are two of these three-roller mills and in some three. The rollers are so arranged that two are placed on a level and geared to move in the same direction while the third moves in the opposite direction. If a factory operates two mills, the rollers of the first are farther apart than those of the second, and if three mills, the third has its rollers closer together than the second. These rollers revolve very slowly (one and a half to two and a half revolutions per minute) and are operated under great pressure. To relieve the strain upon the mill, a cane crusher or shredder has come into general use. The cane enters one of these as it leaves the cane carrier and is either crushed or shredded into small pieces before reaching the mill. This not only relieves the mill of the work of crushing the whole cane, but increases its capacity. The capacity of mills will vary from 200 to 1,400 tons of cane per day and the extraction is 70–80 per cent of the weight of cane and 90–95 per cent of the sugar in the cane. Between the first and second mill the juice receives a spray, through a perforated pipe, of either hot or cold water, the object being to dilute the sugar so that a large percentage will be crushed out by the second mill. This addition of water is termed

maceration, and the quantity of water added may vary from 5 to 15 per cent of the weight of the cane and in some cases as much as 20 per cent, the quantity depending somewhat upon the value of fuel and the capacity of the evaporating outfit. In some instances the diluted juice from the third mill is returned and used for macerating the crushed cane between the first and second mill, and water is used between the second and third.

Diffusion has been practiced at several factories in Louisiana and some other countries, but it has not yet met with very great favor.

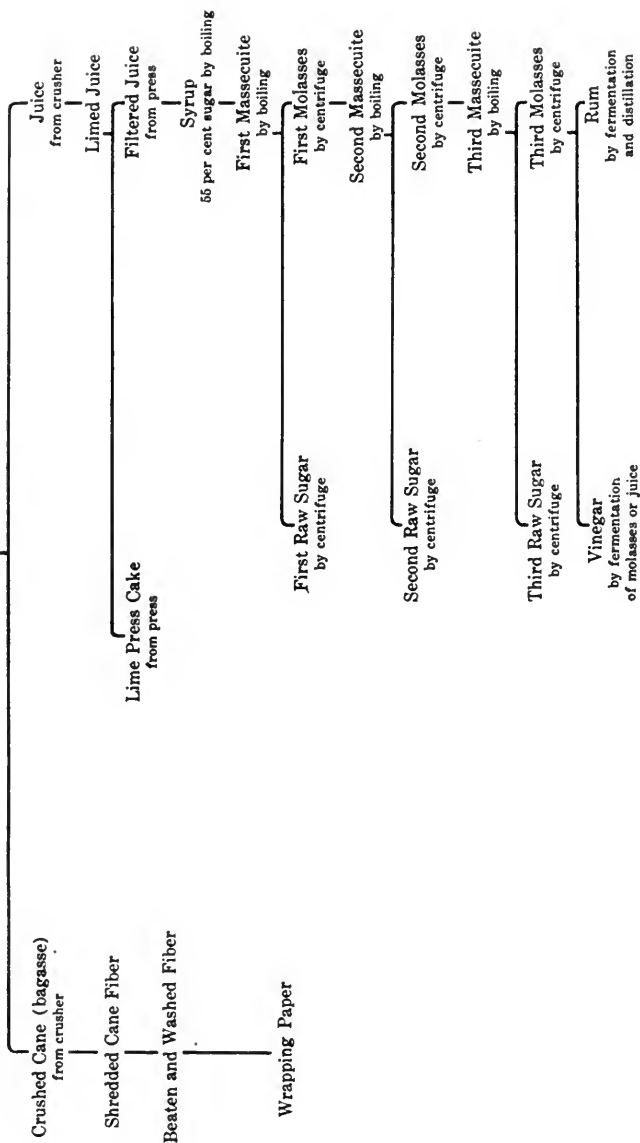
Purification of the juice.—The juice as extracted by the mill has a gray or dark-green color, an acid reaction, and contains sucrose, glucose, perhaps a little levulose, gum, protein, organic acids, pectin, ash or mineral constituents, soil, coloring matter, fine particles of suspended cane, etc.

Primitive methods for purifying the juice do not differ essentially from the practice of today. The juice extracted in crude mills was heated in an iron vessel over a wood fire. Ashes from the fire were added to the hot juice. A dark scum was thus caused to form and was removed. The juice was concentrated by boiling to a thick syrup and slowly cooled. This practice is still employed in China and India. The chemical action of wood ashes is now easily explained by its alkaline constituent, carbonate of potash, which precipitates certain non-sugars in the juice and forms a dark scum.

For large-scale manufacture more economical methods of heating the juice were evolved. Steam heat was first employed in 1785. Other alkalies soon came into use, for instance, carbonate of soda, which is used in India to the present day. The cheaper alkali,

CANE SUGAR MANUFACTURE

Crushed Sugar Cane



slaked lime, was first employed in addition to wood ashes in 1750 and finally substituted for it.

In the modern factory, the object of the chemical treatment is threefold:

1. *Clarification* by the precipitation of dissolved non-sugars.

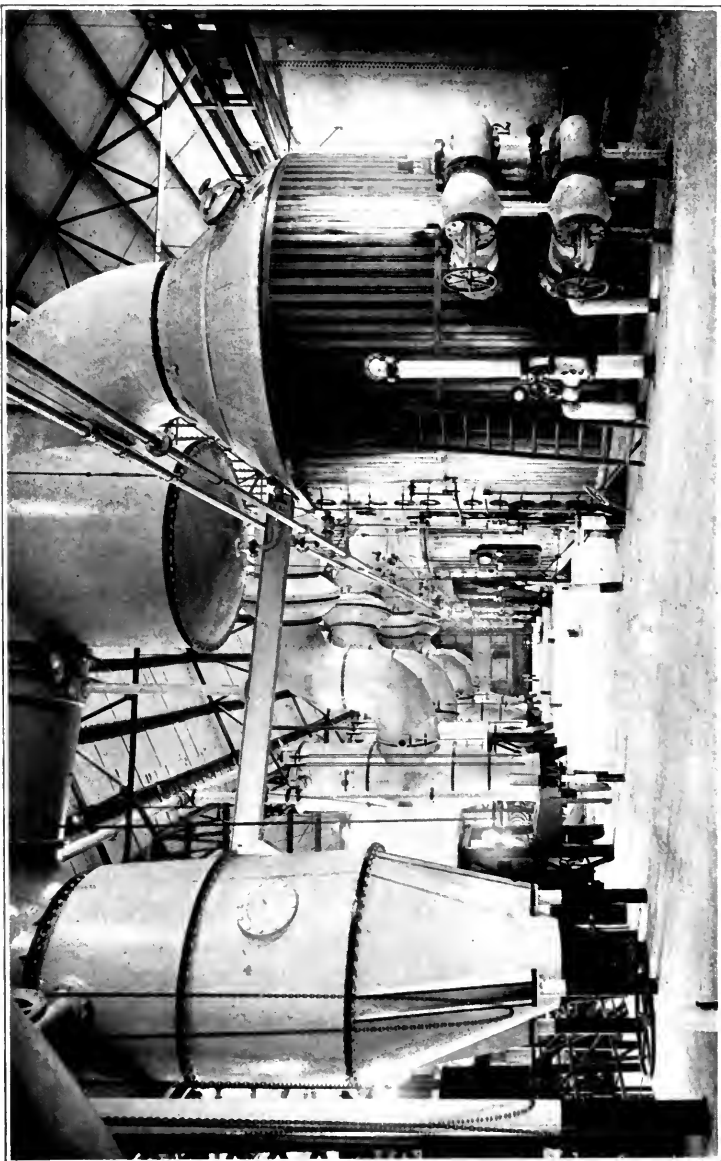
2. *Defecation* or the separation of insoluble solid matter which has not been removed by the filter but remains suspended in the juice.

3. *Refining*. This treatment is only adopted in the manufacture of white and yellow sugars intended for direct consumption.

The purpose of clarification is to remove the impurities as far as possible. This is accomplished by chemicals and heat, causing the soluble impurities to become insoluble so that they may be removed by settling or filtration. The principal chemicals are sulphur, lime, and phosphoric acid. Sulphur is applied as sulphur dioxide which bleaches, disinfects, and coagulates some of the protein and prepares the juice for taking more lime, thereby causing a heavier precipitation which brings about a mechanical cleansing. Sulphur is not much used in the tropical countries where the juice is of a high degree of purity, but it is extensively used in Louisiana and other sections where the juice contains large portions of impurities. Lime is universally used and is the most important of all the chemicals employed in a sugar factory. It neutralizes acids, acts upon the gums, protein substances, coloring matters, and, if added in excess, upon the glucose, converting it into organic acids. The lime compounds thus formed are largely insoluble, the insoluble portion is removed by settling or filtration and much of the soluble can be gotten rid of by the addition of phosphoric acid or sodium carbonate, to form the insoluble lime salts. Phosphoric acid is also used

to correct any alkalinity resulting from excessive liming, and sodium carbonate is very essential in properly correcting the acidity of sour juices. Lime salts, if left in solution in any considerable quantity, give trouble by depositing on the coils of the "effects" and "pans," thereby reducing their efficiency in the evaporation. Carbon dioxide is used to correct alkalinity and remove excess of lime.

To carry out the process of clarification, the juice is strained through a copper-wire gauze as it leaves the mill, then drawn into a sulphur box or tank, if sulphur is used, where it is thoroughly mixed with sulphur dioxide which is produced by the burning of sulphur in an appropriate oven near by. From the sulphuring apparatus which may consist of a box in which the juice and "sulphur gas" are mixed by a pump, or of a cylindrical rotating and inclined vessel in which the mixing takes place by rotation, the juice is drawn into measuring tanks. The clarifiers are large rectangular or circular metallic pans, provided with a steam coil. In some cases the juice is heated before entering the clarifiers, in others it is heated in them. Milk of lime, prepared by slaking and grinding, is added to the juice in the clarifiers in sufficient quantity to neutralize it, or leave it slightly acid or alkaline. This is done in accordance with the practice of the factory, acid juices being worked to produce high-grade sugar and alkaline or neutral to produce low grades. On heating the limed juice a portion of the impurities rise to the surface, while others fall to the bottom. It is the custom in some factories to filter through heavy canvas bags (one folded within another) the entire volume of juice, that is, the partially clarified juice, the muddy portion being conveyed to filter presses, arranged with cloths that fit in between cast-iron plates. The juice is pumped into the



Courtesy of the United Fruit Co.

VACUUM PANS FOR CONCENTRATING CANE JUICE IN CUBA.

filter press where these cloths retain all the solid particles. In recent years there has been added to the ordinary process a super-heating apparatus by which some of the soluble material is converted into insoluble material at a temperature 15–30° Fahrenheit above boiling.

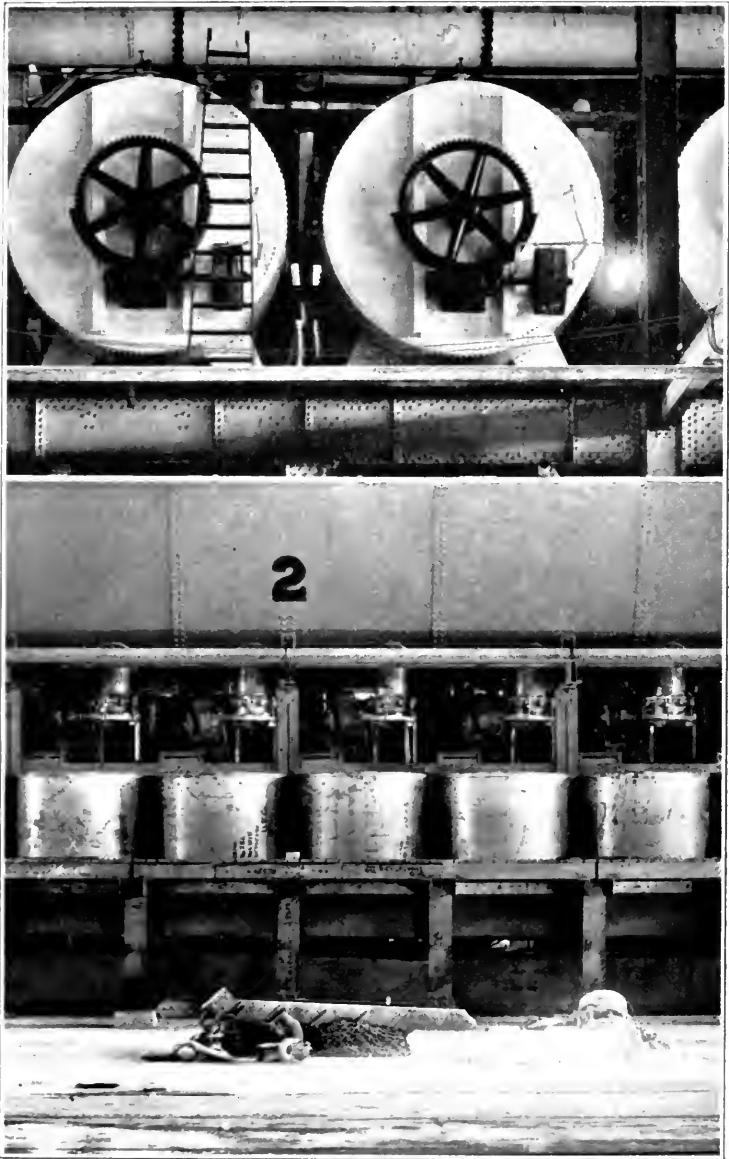
Evaporization and crystallization.—The evaporation of sugar solutions or cane juice has for its object a concentration of the liquid to such density as will cause the sugar to crystallize out. To accomplish this there are two methods, the “open kettle” and the vacuum pan. The open-kettle process consists in boiling the juice in open pans, either of circular or rectangular form, provided with steam coils. The heat is continued until the density indicates sufficient cooking. When a density of 22° or 36° Baumé is reached, the liquid is termed a syrup, and when the syrup is cooked to a stiff mass, massecuite. After allowing crystallization to take place in wood or iron vats, the massecuite is thrown into a hogshead and the molasses percolates through a perforated bottom, or the sugar and molasses may be separated in a centrifugal machine. The sugar thus made is termed open kettle, and the process is not used in the up-to-date factory.

The vacuum apparatus for evaporating sugar solutions consists of a dome-shaped vessel, provided with coils of steam pipes and requires only about one-third the fuel of the open-kettle process and reduces to a minimum the loss by burning or inversion to glucose and fructose.

The syrup is drawn from the syrup tank into the vacuum pan until one, two, or three coils are covered, and this definite quantity is heated until grains of sugar may be seen on withdrawing a sample and spreading it on a piece of glass. The formation of crystals is sometimes brought about by permitting a

little cold juice to enter the pan and suddenly cool it. The object here is to form a crop of "seed crystals," and the remainder of the process has for its purpose the increase in size of the crystals to a desired point. This is accomplished by continuing the boiling and adding, from time to time, small quantities of the syrup, taking care that no more grains or crystals are formed. In three to four hours the pan will be as full as is convenient to cook it and the sugar crystals as large as desired. If very large crystals are wanted, as is sometimes the case with confectioners' sugar, a "cut" strike is made. That is, one-third or one-half the sugar in the pan is removed and the remaining portion is built up in the same manner as already described. On completing the boiling the second time there are not so many crystals, but they are twice as large. This process may be repeated, but it is very expensive. The cooking is continued until the concentrated mass contains 6-8 per cent of water. The discharging of the pan is termed a "strike," and the product discharged, massecuite. This is conveyed to a mixer provided with a shaft carrying paddles or fingers that keep the sugar and adhering molasses mixed. The well-mixed massecuite is next conveyed to a centrifugal machine, made to revolve 1,000 to 1,200 times per minute, and in its rapid motion the sugar and molasses are separated, the latter being ejected through very small perforations, while the sugar remains in the basket. The product thus obtained is termed "first sugar," or "raw sugar," and is usually of 96 per cent purity.

The utilization of bagasse.—The cane, after receiving its final crushing (bagasse), whether passed through two or three mills, contains from 40 to 50 per cent of water and is, therefore, a poor fuel if its value be estimated on the weight of bagasse. Even though



Courtesy of the United Fruit Co.

CENTRIFUGAL MACHINES FOR CANE SUGAR IN CUBA.

it is poor fuel it is used as such for if allowed to accumulate it would become a great nuisance about the factory. If the ash contains silica and alkalies in proportion to form a fusible mixture, a slag will result and choke the furnace by forming a coating over the gratings; for this reason the burning of a mixture of bagasse and molasses has not been satisfactory. Notwithstanding its high water content, it supplies about two-thirds of the fuel in the Louisiana sugar factory and practically all of it in the tropical countries where the bulk of fiber is from 2 to 3 per cent greater.

Bagasse can also be made into paper. The first patent for paper manufacture from bagasse was issued in 1838. The first large-scale experiment was carried on in Texas in a sugar factory. This was a commercial failure and was abandoned. The experiments on the Tacarigua Estate, Trinidad, were more successful. There bagasse was mixed with bamboo and Para grass and made into paper. The manufacture of this paper was carried on in 1915 by a sugar factory in Cuba. Improvements in the process have resulted in the making of "wall board" and paper suitable for newspaper and better grades of wrapping paper.

BEET SUGAR

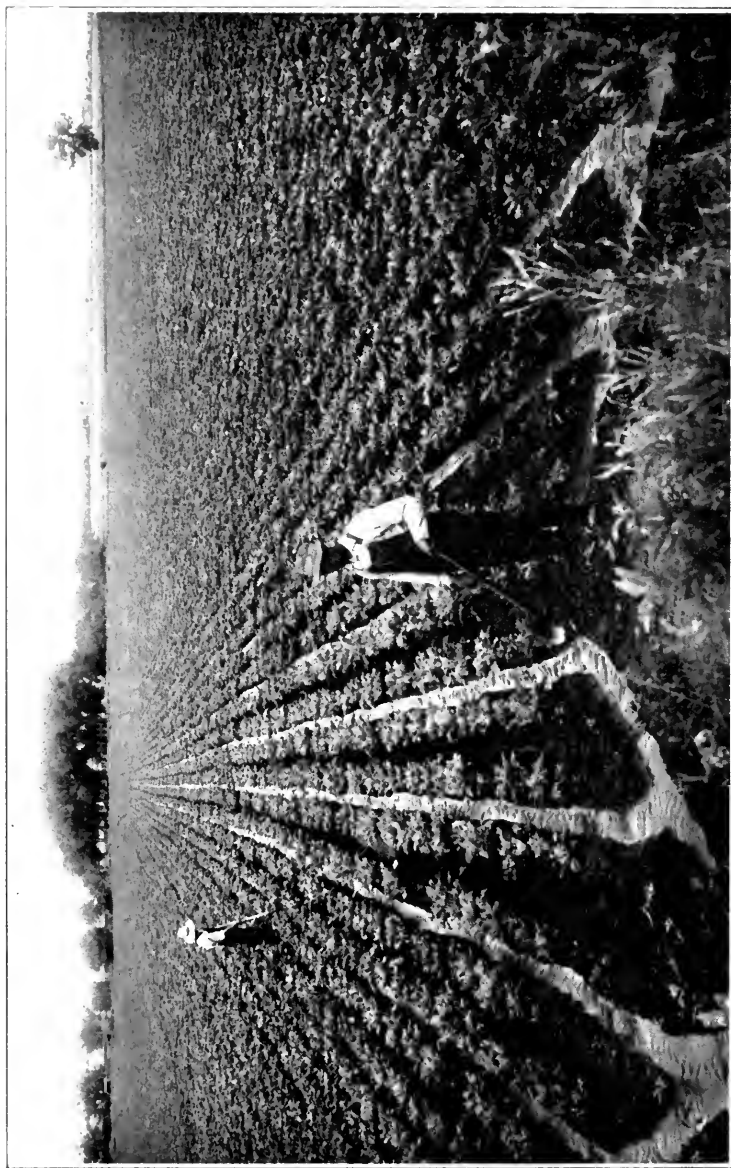
Sugar was noticed in the ordinary beet in 1590 by Oliver des Serres, but received no further attention as a source of sugar until Margraff, a member of the Berlin Academy of Science, in 1747, conducted an investigation of the sugar content of various plants. The sugar content of the common garden beet is very small, being from 2 to 4 per cent. The sugar beet is a variety of this derived by selection and cultivation from the wild beet of the coast of Europe.

Great interest in both Germany and France followed the investigation of Achard in 1799 and by

1812 there were many factories established. Napoleon added greatly to the progress of this industry by government aid and by the establishment of sugar schools. After the new industry had become well established, it was almost obliterated by destructive wars. It was, however, soon revived in France and by 1829 a yield of 4,000 tons of sugar was made, but Germany's interest was not resumed until 1835. From these countries the industry has spread throughout Europe until the production for 1924-25 has been estimated at 8,957,289 short tons for the world of which the United States produced 1,172,000.

The first experiments with sugar beets in the United States were made by two Philadelphians in 1830. About ten years later David Lee Child, Northampton, Massachusetts, attempted beet culture and the manufacture of beet sugar. He produced 1,300 pounds at a cost of eleven cents per pound. These enterprises failed and seem to have discouraged further efforts until Gennert Brothers, natives of Brunswick, Germany, inaugurated a plant at Chatsworth, Illinois, in 1863, which failed, and it may be said that this industry was not permanently established until between 1875 and 1880. From this time sugar beet culture has been successfully conducted in the United States.

Extraction.—The beets are first washed in tanks. From the washing tanks, the beets are carried to a slicing machine, where they are cut into very thin, narrow pieces so that when the chips fall they will not lie too compactly one upon the other. The chips are conveyed from the slicing machine to a hopper feeding a battery of twelve to fourteen cast-iron cylindrical cells connected with each other by a system of pipes with cocks between, so that one may empty and fill without interfering with the operation of the rest.



Courtesy of the Great Western Sugar Co.

IRRIGATING A COLORADO BEET FIELD.

The extraction of the sugar consists in washing the chipped beets with hot water. When the sugar has been extracted from the beets, the bottom of the cell is opened and the beets discharged and led to a press where most of the remaining water and sugar are pressed out. The pulp cake is used in the wet condition for cattle food or it may be dried by means of the exhaust steam so it can be preserved for the same purpose. It may also be used as a fertilizer.

The purification of the extracted sugar solution consists of the application of lime, carbon dioxide, and sulphur, together with settling and filtering. The use of the lime followed by carbon dioxide is termed carbonation. These two materials, lime and carbon dioxide, are obtained by burning limestone in a kiln constructed for that purpose at the factory. The limestone is decomposed and the lime, mixed with water, is added to the sugar solution in a quantity equal to 2 or 3 per cent. The gas is led from the lime kiln through water to wash it and admitted into a large cell provided with coils of steam pipes so the solution may be heated. The temperature at which the carbonation is carried on is 176–94° Fahrenheit. This process of adding lime, then charging with carbon dioxide, is repeated two or three times, depending upon the quality of the juice, but after the first treatment the juice is filtered each time before repeating the carbonation. Finally the juice is treated with sulphur dioxide, which is used to bleach the solution, and then the excess of this gas or acid is removed by the addition of lime and the juice is again treated with carbon dioxide. Before filtering, the juice is allowed to settle so that the impurities may collect at the bottom of the settling tank. The clear liquid is drawn off and filtered through bags. The clarified juice is treated the same as that of cane sugar.

The molasses containing 40–50 per cent of sugar, discharged by the centrifugal, must be treated for the sugar which it contains, though some of the cane sugar molasses is sold to merchants for direct consumption as table molasses, or to confectioners and to glucose mixers for the preparation of glucose syrup. Generally, this molasses is recooked over and over again until all of the crystallizable sugar has been separated. The first reboiling yields “second sugar” and “second molasses,” the second reboiling “third sugar” and “third molasses,” etc. The massecuite is returned to the centrifugal, and the crystals separated from the molasses. The second sugar may be sold to the refineries, but as it falls below the 96 per cent sugar (probably the most profitable grade), it is melted in hot sugar juice and turned out as first sugar. The second molasses is reboiled to “string proof,” put into large tanks and allowed to remain at rest from four to six months, when the crystallized mass is subjected to centrifuging. The third molasses usually contains a large portion of impurities which may make it unprofitable to reboil it further, though some work this molasses for fourth sugar. All of the foregoing grades of sugar recovered by reboiling may be worked back into a first sugar or sold to the refineries.

The refuse or exhausted molasses, which amounts to from four to five gallons per ton of cane and carries 25–40 per cent sugar, has increased very much in value in recent years, selling at six to ten cents per gallon. Some of it is fed to stock and some consumed by distillers.

REFINING OF CANE AND BEET SUGAR

White-sugar loaves were first manufactured from cane sugar many centuries before the introduction of the present refining process which was probably de-

rived from the Arabs. Boiled sap was allowed to crystallize in conical molds, and the mother-liquor drained through a hole in the point. Such sugar loaves were first imported to Great Britain in 1319, and appeared at the coronation banquet of Henry V in 1413.

In 1812 Howard, the inventor of the vacuum pan, patented the use of saturated sugar solutions for washing the sugar loaves in place of the old process of claying. Purification by recrystallization was adopted as early as the thirteenth century. Some of these recrystallized loaves were exported from Cypress, Rhodes, Syria, and Alexandria between 1250 and 1400. The present system of refining is based on this principle, but with the addition of a decolorizing process applied to the solution of raw sugar before recrystallization. The bleaching agent—bone char—first used for decolorizing vinegar in 1810 was later applied to sugar. The next improvement was carbonation which the cane sugar refiners borrowed from the beet sugar manufacturers.

COMPARISON OF CANE AND BEET SUGAR

No one can distinguish between highly refined cane and beet sugar, as they are one and the same thing. Between the crude or raw beet and cane sugar there is a great difference, the latter being edible whereas the former is not, as it possesses a very disagreeable odor and taste. Cane sugar molasses is good for culinary purposes, beet sugar molasses is unsuitable.

MAPLE SUGAR¹

Maple sugar production is an industry almost entirely confined to Northeastern North America. The

¹Other deciduous trees have been tapped for sugar. The butternuts and birches were made use of in this way by some of the early American colonists.

manufacture of this sugar was known to the Indians, for Jeffreys, 1760, says that in Canada "this tree affords great quantities of a cooling and wholesome liquor from which they make a sort of sugar," and Jonathan Carver, in 1784, says the Nadowessie Indians of the West "consume the sugar which they have extracted from the maple tree." In 1870, the Winnebagoes and Chippewas are said to often sell to the Northwest Fur Company 15,000 pounds of sugar a year. The sugar season among the Indians is a sort of carnival, and boiling candy and pouring it out on the snow to cool is the pastime of the children.

The following paragraph is from a book written by the eminent Robert Boyle (the discoverer of Boyle's Law) and printed at Oxford in 1663:

There is in some parts of New England a kind of tree . . . whose juice that weeps out of its incisions, if it be permitted slowly to exhale away the superfluous moisture, doth congeal into a sweet and saccharin substance, and the like was confirmed to me by the agent of the great and populous colony of Massachusetts.

Maple sap contains 2-6 per cent of sugar and averages about 3 per cent. Eighty to 90 per cent of all maple sugar is made from the sap of four species: the sugar maple (*Acer saccharum*), the black maple (*Acer nigrum*), the red maple (*Acer rubrum*), and the silver maple (*Acer saccharinum*).

From nine to fifty-seven days of the year are used in gathering maple sap with an average of thirty-four days per year. The season lasts from the middle of March to the middle of April from Vermont to New York. In Ohio and western New York it extends from late February to early April.

The yield of sap varies considerably with the season, size of tree, character of tapping, and many other conditions. A tree averages a yield of three pounds



Photograph by Laura Dewart.

TAPPING SUGAR MAPLES IN VERMONT.

of sugar per season and may vary from one to seven pounds per tree. From five to forty gallons of sap may be had yearly from each tree. Thirty-two gallons of sap are made into one gallon of syrup and four and a quarter gallons of sap contain one pound of sugar.

To make the sugar, the syrup is heated until it is so thick that it pours slowly or becomes waxy in the snow or in cold water or reaches a temperature of 230° Fahrenheit. It is then poured into molds. The first run of sap always makes the best sugar and the last of the season sometimes fails to "cake." During the heating, scum is taken off the surface by skimming; the sap gradually turns to an amber color as it reaches the syrupy stage and deposits malate of lime (called "niter" in Vermont and "silica" in Ohio).

In 1860 the total production of maple sugar and syrup in the United States reached its height. It fell heavily in 1870, arose again to large proportions in 1880, remained stationary in 1890, and then suddenly fell almost 50 per cent in 1900, when the total amount produced was nearly one-third less than in 1850. The quantity produced in 1923 was about one-half that of 1900 and amounted to 4,685,000 pounds of sugar and 3,605,000 gallons of syrup. This reduction has been caused in part by the felling of the trees for lumber, etc., insect attacks, adulteration, and the decrease in the price of cane sugar.

COMPARISON OF CANE AND MAPLE SUGAR

By 1875 cane sugar became cheap enough to undersell that of maple. Since 1885 maple sugar has been a luxury only. In this capacity its prospects are much better than formerly although the adulteration of maple syrup with glucose and cane sugar has tended to keep down the price of maple sugar.

SORGHUM SUGAR

The stem of the Guinea corn, or sorghum (*Sorghum saccharatum*), has long been known in China as a source of sugar. The sorghum is hardier than the sugar cane; it comes to maturity in a season; and it retains its maximum sugar content a considerable time, giving opportunity for leisurely harvesting. The sugar is obtained by the same method as cane sugar.

Many experiments have been made to produce sugar from sorghum on a commercial scale but the results have not been profitable. There is now very little, if any, sugar made from sorghum, although there is considerable syrup.

PALM SUGAR

Palm sugar which comes into the European markets as *jaggery* or *khaur* is obtained from the sap of several palms, the wild date (*Phoenix sylvestris*), the palmyra (*Borassus flabellifer*), the cocoanut (*Cocos nucifera*), the gomuti (*Arenga saccharifera*), and others.

The palm sugar industry of India is a very old one, but insignificant compared with the sugar-cane industry of that country. A fair estimate places the annual production of Indian palm sugar at about 100,000 tons.

The sap of the palmyra and cocoanut palms is obtained from their young flowering branches. These palms do not bloom until they are from twelve to fifteen years old. The sugar-gathering season which lasts for several months commences with the appearance of these branches or spadices in November or December. The spathes are bruised and cut, and their juice or toddy caught in a suspended chatty or toddy receiver. A spadix continues to give toddy for about five months,



"TODDY TAPPERS" READY TO COLLECT PALM SAP IN INDIA.

at the rate of three or four quarts a day. Seldom more than three spadices yield toddy on the cocoanut tree at the same time, but seven or eight will yield juice at once on the palmyra palm. An expert climber can draw toddy from about forty trees in a few hours. It is said that if the operation be repeated on the same tree for three successive years, without allowing any of the buds to bloom, the tree will die.

To obtain sugar from the sap, the "toddy" is boiled until it becomes a thick syrup. It may then be poured into small baskets of palmyra leaf to cool and harden into "jaggery," or it is formed into round cakes and wrapped in pieces of dried banana leaves. About three quarts of toddy are sufficient to make one pound of crude sugar or jaggery.

Other palms of which the juice of the spadices is a source of sugar are: the fish-tail palm (*Caryota urens*), the gomuti palm (*Arenga saccharifera*), and the African oil palm (*Elaeis guineensis*).

The wild date palm (*Phoenix sylvestris*) is tapped for its sap as a source of sugar quite similarly to the maple tree. In many localities, especially in Jessore and other districts of Bengal, the wild date palm is of importance in this regard. In 1889, some 168,262 acres were under cultivation here. The following account of the process of tapping the trees and of the manufacture of sugar from the sap comes from Sir James Westland.

When the tree becomes six or seven years old tapping begins and is continued each year thereafter. When the rainy season has completely passed, the cultivator cuts off the lateral leaves of one-half of the circumference, and in this manner leaves bare a surface measuring about 10 or 12 inches square.

After the tree has remained in this condition for a few days, the tapping is performed by making a cut

into this exposed surface, in the shape of a very broad V, about three inches wide and a quarter or half inch deep. Then the portion inside the angle of the V is cut deeper, so that a triangular surface is cut into the tree. From this the sap exudes. Caught by the sides of the V, it runs down to the angle, where a bamboo of the size of a lead pencil is inserted in the tree to catch the dropping sap and carry it out as by a spout.

The tapping is arranged throughout the season in periods of six days each. On the first evening a cut is made as just described, and the juice is allowed to run during the night. This juice is the strongest and best, and is called jiran juice. In the morning the juice collected in a pot hanging beneath the bamboo spout is removed. The flow of juice stops during the day. So in the evening a new cut is made, not nearly as deep as the last, but rather a mere paring, and for a second night the juice is allowed to run. This juice is termed do-kat and is not quite so abundant or so good as the jiran. The third night no new cutting is made, but the exuding surface is merely made quite clean, and the juice which then runs is called jarra. It is still less abundant and less rich than the do-kat, and toward the end of the season, when the weather is getting hot, it is unfit even for sugar manufacture, the gur (molasses) made from it being sold simply as "droppings." These three nights are the periods of activity in the tree, and after these three it is allowed to remain for three nights at rest, when the same process is repeated. Of course, every tree in the same grove does not run in the same cycle, some are at their first, some at their second night, and so on; and thus the owner is always busy.

Since every sixth day a new cut is made over the previous one, the tree gets more and more hewed into as the season progresses, and toward the end of the

season the exuding surface may be, and often is, as much as four inches deep. The cuts during the whole of one season are made about the same place, but in alternate seasons alternate sides of the tree are used for the tapping; and as each season's cutting is thus above the previous season's and on the opposite side, the stem of the tree has a curious zigzag appearance. The age of a tree can of course be at once counted up by enumerating the notches and adding six or seven, the number of years passed before the first year's notch. More than forty notches have been counted on a tree, but one rarely sees them so old. When they are forty-six years old they are worth little as sugar-producing trees. It is somewhat remarkable that the notches are almost always on the east and west sides of the tree and very rarely on the north and south sides; also that the first notch appears to be made on the east side in by far the majority of instances.

One may expect from a good tree a regular average of five pints of sap per night (excluding the quiescent nights). The colder and clearer the weather, the more copious and rich the juice. In the beginning of November tapping begins. In December and January the juice flows best, beginning sometimes as early as 3 P.M., and decreasing with the coming of the warm days of March. If the cultivator begins too early, or continues too late, he will lose in quality and quantity as much as he will gain by extending the tapping season.

The next process is the boiling, and this every rayat does for himself, and usually within the limits of the grove. Without boiling, the juice speedily ferments and becomes useless; but once boiled down into gur, it may be kept for very long periods. The juice which was at first brilliant and limpid, becomes now a dark-brown, half-viscid, half-solid mass, and

when it is still warm, it is easily poured from the boiling-pan into the earthenware pots in which it is ordinarily kept. As it takes from seven to ten pints of juice to produce one pint of gur or molasses, one can calculate the amount of gur which a good tree can produce in a season. One may count four and a half months for the tapping season, or about sixty-seven tapping nights. These, at five pints each, produce 335 pints of juice, which will give about forty pounds of gur.

After the juice is boiled down into gur it is then sold to the sugar-refiners and by them is manufactured in various ways into different grades of sugar. The best known is called dhulva, a soft, moist, powdery sugar, used largely in the manufacture of native candies. Another kind, termed pucka, is purer, granular, and more expensive. The waste molasses, collected during the preparation of sugar, is called chitiya gur. When boiled for a longer time, it becomes a black, sticky treacle, which is largely utilized for mixing with tobacco for the native hookah, and also for making cheap candy. A small proportion of the juice is consumed as a drink either fermented or unfermented, under the name of tari, or is converted into vinegar.

OTHER SUGARS

Malt sugar preparations.—A sweet material called "ame" has been made in Japan since early times from glutinous rice or glutinous millet, sometimes from common rice and rarely from Indian corn or sweet potatoes. Ame is made from these by converting their starch into maltose by the action of an enzyme called diastase. Sprouted barley is generally used to furnish the enzyme. In making ame the grains or potatoes are first cleaned, then soaked in water and steamed until the starch grains are broken and made easily ac-

cessible to the enzyme. Powdered malt and water in proper proportions are now added, and in six or eight hours the diastase converts most of the starch into dextrin and maltose. The liquid is then filtered and evaporated to the desired consistency. One of the forms is a dense, clear, light-colored amber liquid. Another form is hard and quite similar to white candy in appearance. Ame has been made in Japan for at least two thousand years, and long before cane sugar was known it was a favorite flavoring. Even at the present time it is sometimes used instead of sugar in cooking and it also makes a favorite addition to the food of invalids.

Several malt preparations, some of them thick like syrup and others more of the consistency of candy, are on the market. These are mixtures of dextrin and maltose coming from the action of diastase on starchy materials. Many commercial products, such as those called "predigested" and "malted," have this material as their basis.

Glucose.—Glucose is manufactured in large amounts in the United States from corn-starch, and is sold for table syrup and other purposes. It is prepared by a chemical process which consists of hydrolyzing the starch into glucose by means of dilute acid and pressure. Frequently part of the output of a glucose plant is blended with maple syrup or other flavoring material. The resulting mixtures are palatable and nutritious but do not have the body-heating value nor the sweetness of syrups having the same percentage of cane, maple, and sorghum sugar.

Miscellaneous sugars.—Other sugars which before 1914 were largely or entirely imported, but which are now made in the United States in amounts sufficient for local needs, are *lactose* (milk sugar) used in the preparation of infant foods, etc.; *levulose*, used in place

of cane sugar in the foods of persons suffering from diabetes, etc.; and the so-called "rare" sugars, such as *maltose*, *mannose*, *xylose*, *melezitose*, *melibiose*, *trehalose*, *rhamnose*, etc., used almost solely in chemical and bacteriological investigations. The production of these sugars varies from about 6,000,000 pounds in the case of lactose to possibly less than one ounce in the case of some of the rare sugars, and the price varies from about twenty cents per pound in the case of lactose to twenty-five dollars or more an ounce in the case of certain of the rare sugars.

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Exhibits illustrating the processes of cane and beet sugar-making, together with specimens of various sugars, are to be found in the economic exhibits of the Department of Botany on the south side of Hall 25 in the Museum. The various palms mentioned are on the north side of the same Hall. A flower of the "Boer Honey Pot" may be seen in the Hall of Plant Life (Hall 29).

