Workers in a candy factory in Sri Lanka busily pack their morsels for shipment to distant markets.
Hank Walker/Time & Life Pictures/Getty.

# 9

# Carbohydrates: Sugar

Chapter Contents



## Key Concepts

1. Mono- and disaccharides, which are simple carbohydrates capable of undergoing hydrolysis and caramelization, are available in a variety of products to sweeten food products.
2. Several alternative sweeteners have entered the market to provide sweetness in various products with reduced calories from carbohydrates.
3. Crystalline candies are made by creating a supersaturated solution and then controlling cooling and crystallization to produce a smooth texture.
4. The sugar solution in amorphous candies reaches such a high temperature and concentration of sugar that an organized crystalline structure cannot form.

## INTRODUCING THE CARBOHYDRATES

**Carbohydrates** are recognized in nutrition as an important source of energy, a function viewed negatively by some weight-conscious people. It is true that some foods are rather concentrated sources of carbohydrate, but pure carbohydrates still provide less than half as many calories per gram as are derived from a comparable amount of pure fat.

In food preparation, the various carbohydrates serve some key roles meriting special discussion. The simplest of the carbohydrates are the sugars. Many foods, particularly fruits, naturally contain sugars, which are responsible for pleasingly sweet flavors. However, sugars in various forms often are added when making candies, desserts, and even sauces for meats and vegetables.

Other carbohydrates that are larger molecules than sugars also are found in a wide array of foods. Starch is perhaps the most familiar complex carbohydrate, but the fiber in fruits and vegetables also contains carbohydrates in such forms as cellulose, hemicelluloses, pectic substances, and gums. These different forms are valued in food preparation for their contributions to the texture and structure of foods.

At first glance, it would seem that sugar and its sweet flavor would have almost nothing in common with the complex structural carbohydrates that contribute a range of textures. Why are these simple and complex substances clumped collectively into the category of organic compounds called carbohydrates? The answer lies in the fact that they are all made up of the same elements—carbon, hydrogen, and oxygen—and in approximately the same proportions. The term *carbohydrate* is a combination of *carbon* and *hydrate* (H and OH, or water). This relationship of hydrate to carbon holds regardless of the size and complexity of a particular carbohydrate.

***carbohydrates*** Organic compounds containing carbon, hydrogen, and oxygen, with the hydrogen/oxygen ratio being the same as water ($H_2O$); includes sugars, starches, pectic substances, cellulose, gums, and other complex substances.

## SUGARS IN THE MARKETPLACE

The sugars marketed today are quite different in quality, quantity, and price from the first sugar known in the Near East. Although sugar was once a rare item available only to royalty, today it is a household item in most kitchens around the world. The history of sugar began sometime between 300 and 600 A.D. when various techniques were developed in the Near East to refine and crystallize sugar. News of this remarkable food was carried to Europe by the returning Crusaders and eventually reached the New World when Columbus introduced sugar to Santo Domingo in 1493.

Of course, changes in sugar production have taken place over the centuries, but perhaps the single most important discovery was the realization by a 19th-century German chemist that the sugar beet is an outstanding source of sugar. By the beginning of 20th century, the sugar beet was approaching sugarcane as a source of sugar for commercial production. Levels of consumption of cane versus beet sugar vary in different sections of the country.

Cane sugar is produced by washing the cane stalks, squeezing out the juice from the cane stalks (Figure 9.1), heating the juice in the presence of lime to aid in removing impurities, and then evaporating the mixture to a highly viscous syrup and to raw sugar crystals (Figure 9.2). These raw sugar crystals are the starting material for the refining process. The coarse, yellow raw sugar is transformed from its sticky state into white, fine crystals by the use of charcoal and careful control of the crystallization process.

Beet sugar, the product of sugar beets, is extracted from these beets and processed to the refined sugar product in much the same manner as the process used for making cane sugar. The end product of both of these manufacturing processes is the same sugar, sucrose, and is marketed simply as granulated sugar or in related sugar products. Since there is no difference between cane and beet sugars, either type can be chosen. The market for both types is regulated by the federal government, which establishes the levels of sugar imports authorized each year.

An interesting by-product of sugar manufacturing is monosodium glutamate, often referred to simply as **MSG**. This is a sodium derivative of sugar, yet is not itself sweet tasting. Its merit is as a flavor enhancer to help heighten the existing flavors in foods. It is a familiar ingredient in various Asian cuisines.

***MSG*** Monosodium glutamate (MSG), a by-product of sugar processing, is a flavor enhancer often used in Asian cuisines.

### Granulated Sugar

Between 50 and 85 percent of factory sugar production is devoted to granulated sugar because of its important roles in many food products. The source of granulated sugar, whether cane or beet, will be found on the package label, although both products are the same.

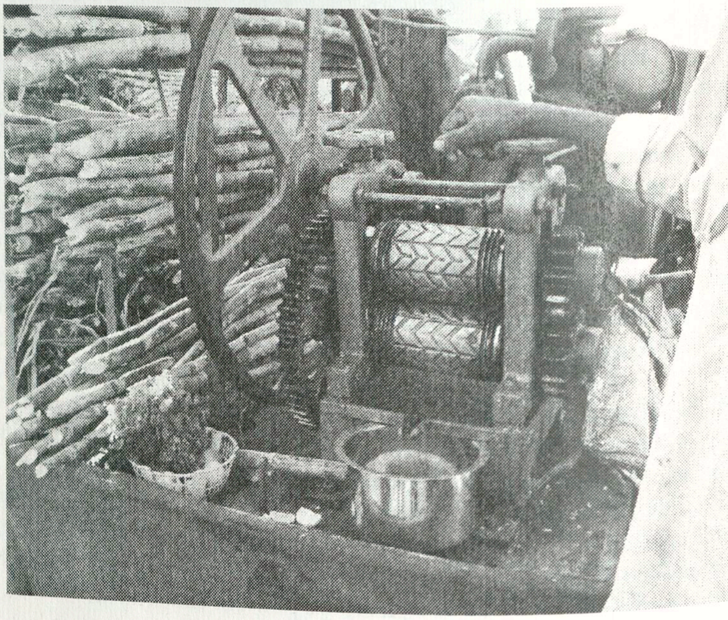


***Figure 9.1***
Juice is squeezed from sugarcane as the first step in manufacturing cane sugar.
Plycon Press.

*Figure 9.2*
Balls of unrefined cane sugar are ready to go to the market in India, where they are called jaggery. Plycon Press.

White or refined granulated sugar may be purchased in different granule sizes, ranging from superfine to regular granulated sugar. The name dessert sugar, a synonym for superfine, indicates that this type of sugar is preferred for making hard and soft meringues and other desserts where the ease of solubility of these very tiny crystals is important. Regular granulated sugar is perfectly suitable for most uses and has the advantage of being less expensive than dessert sugar.

Cube sugar is simply granulated sugar that has been moistened with a colorless syrup, molded into cubes, and then dried in that shape. These cubes are used for sweetening individual cups of tea and coffee.

## Powdered (Confectioner's) Sugar

One problem with any sugar is its tendency to cake when stored in a moist environment. To counteract the tendency to lump when sugar that is pulverized to a fine powder is stored, cornstarch is added in the manufacturing of powdered sugar. A mixture that contains 3 percent cornstarch is sufficient to absorb the moisture that would otherwise cause caking in this sugar with very fine particles. Powdered sugar customarily is used for making icings and for sweetening certain fruits, such as strawberries.

## Raw Sugar

Raw sugar, a semirefined sugar that is a light tan color, has gained a place on the market shelf because of consumers' demand for natural products. However, there is no nutritional merit in using raw sugar in place of granulated sugar. (Raw sugar in the market is not actually the unrefined product, for the unrefined product is not safe to eat and cannot be sold.) Sugar that is marketed in this country as raw behaves much like brown sugar in food preparation and is sometimes used to sweeten fruits or to make cookies and other baked products. The tan color will show when this sugar is used in light-colored baked products. The cost of raw sugar is surprisingly high in view of the fact that the processing is slightly easier than that for white granulated sugar and there are no significant nutritional benefits.

## Brown Sugar

Because of its pleasing and distinctive flavor, brown sugar frequently is used in baked products. The color and flavor of brown sugar are correlated with the state of refinement: a dark, strong-flavored brown sugar has undergone less filtration and purification than has a light, mild-flavored product. Either can be used very satisfactorily. The comparatively high moisture content of brown sugar tends to promote the development of hard lumps during storage. Packaging in plastic bags with tight closures that can be resealed helps to minimize this problem. A pourable, pellet-like brown sugar is also available, although this is more costly than regular brown sugar.

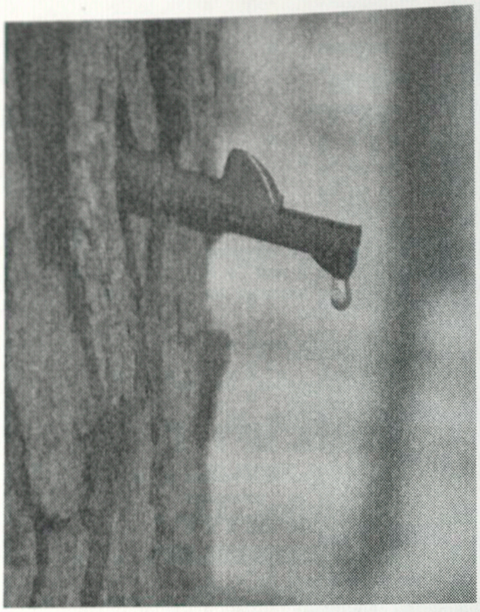


***Figure 9.3***
This tap in a sugar maple tree drips sugary sap as the prelude to maple syrup and sugar. Courtesy of Debra McRae.

## Maple Sugar and Maple Syrup

The tapping of sugar maple trees (Figure 9.3) and boiling of the collected sap to make maple syrup and maple sugar date back to colonial days in America. It still is possible to buy maple syrup and sugar, but limitations in the production process have hampered output and caused prices to be relatively high for these products.

Maple syrup and sugar have a sweet taste and a pleasing, distinctive flavor, which contributes to their popularity. The demand for maple flavoring has stimulated considerable effort to develop a synthetic counterpart, and the result is a reasonably comparable flavoring at a significantly reduced price. Synthetically flavored maple syrup is a familiar and widely used topping for pancakes and waffles and may even be used occasionally in baked products for sweetening.

## Molasses

Molasses is a sugarcane derivative that may be marketed as unsulfured, sulfured, or blackstrap. Sulfured molasses ranges in color from rather light to a medium dark brown, depending on whether it is prepared by centrifuging the first (the lighter color) or second boiling of the sugarcane juice. Sulfured molasses is a by-product remaining after cane sugar has been crystallized and removed from the cane juice. Sulfur fumes are in contact with the liquid when sugar is the principal product being prepared, and molasses is merely a by-product.

Unsulfured molasses is a full-flavored, reddish-brown liquid that has not been exposed to sulfur fumes. Aging enhances the flavor of unsulfured molasses. Blackstrap molasses, often used as animal food, is the material remaining after the sugar has been extracted from the boiled cane juice.

*http://www.international sugars.com/ISI_-_Home.html*
—Information on sugars available for commercial use.

*http://www.mayoclinic.com/health/high-fructose-corn-syrup/AN01588*
—Mayo Clinic discusses high-fructose corn syrup.

*http://www.karosyrup.com/products.html*
—Information on various corn syrups.

***high-fructose corn syrup (HFCS)*** Corn syrup in which isomerase has converted some of the sugar to fructose.

***isomerase*** Enzyme used to convert glucose to fructose to make high-fructose corn syrup.

## Corn Syrup

All of the sweeteners discussed so far are produced from parts of plants that are high in their sugar content. Corn syrup is unique in that it is produced from starch, a complex carbohydrate, by a series of chemical changes called hydrolysis. This hydrolytic breakdown is accomplished by treating starch from corn with hydrochloric or sulfuric acids in the presence of heat and pressure to produce a mixture of breakdown products. Although cornstarch itself does not have a sweet taste, the small units splitting from the starch (glucose, maltose, and some dextrins) are sweet. Corn syrup, which is a very viscous liquid, gains much of its sweetness from its high glucose content. Light corn syrup is light in color (not in calories) and has a slight flavor of vanilla; dark corn syrup has a more intense flavor from a little addition of a molasses derivative. These two can be used to suit the recipe or the preference of the chef, but color and flavor differences will be evident.

The abundance and comparatively low cost of cornstarch are valued qualities that have helped to make corn syrup a popular sweetener. However, there still is a need to find ways of using or marketing the surplus cornstarch available, and this has prompted efforts to derive new products from it. One creative approach has involved the development of a corn syrup called **high-fructose corn syrup**. Chemically, this is an interesting product; the enzyme **isomerase** is used to convert some of the glucose in the corn syrup into another sugar, fructose. Theoretically, this high-fructose corn syrup (actually only about 30 percent fructose) has an advantage over the original corn syrup because fructose is about twice as sweet as glucose. This means that less fructose-containing corn syrup can be used to sweeten a product than would be needed if ordinary corn syrup were used. This difference is an advantage in beverages or other fluid applications but not in baked products. Nevertheless, there are many applications of high-fructose corn syrup by food manufacturers. High-fructose corn syrup is not available directly to consumers at the marketplace level.

### *CONSUMER ALERT*

## CORN SYRUP CONTROVERSY

The crisis over America's weight problems is front and center as a major health issue. Clearly this is an important issue, but weight control is a confounding personal problem for growing numbers of people. As publicity has focused increasingly on weight loss, considerable information is circulating via all possible modes of communication and from numerous people, ranging from leading medical and nutrition authorities to opportunists with strong voices and opinions, but little accurate knowledge.

Sweet foods are frequently the target when weight-loss diets are being devised, which makes sense because of the comparatively high calorie count in relation to essential nutrients. One response to letting people have their cake and eat it too has been the development of several zero- or low-calorie sweeteners. Unfortunately, many dieters seem to think that means the food itself can be eaten in any quantity without adding calories, which ignores the fats that often are included in sweet treats.

The gathering storm regarding sweets in the diet has settled on HFCS, charging that it is the cause of childhood obesity and many related problems. No doubt HFCS has contributed, but so has every other food that was consumed beyond the amount needed for a healthy weight. There is nothing unique about HFCS. Like other digestible carbohydrates, it contributes four kilocalories per gram. People need to reduce intake of foods providing few nutrients in relation to calories. Protesting against HFCS will not solve the problem, but eating less will.

### *INGREDIENT HIGHLIGHT*

## HONEY

Honey is the only sweetener derived from animal sources. Bees, using nectar from different flowering plants, produce this distinctive sweetening liquid (Figure 9.4). Frequently, the sources of nectar for the bees are clover and alfalfa, but there are many types of honey, such as orange blossom, available with varying flavor qualities. Honey is an excellent sweetener because it contains an abundance of fructose and adds a distinctive flavor to products containing it.

The disadvantages of honey are the comparatively high price and the fast browning when batters and doughs containing honey are baked. This difference in the rate of browning is due to the large amount of fructose, which causes more rapid browning than sugar does.

Honey can be substituted in some recipes for as much as half the sugar, but adjustments will be needed. For each cup of honey used, liquid needs to be reduced by one-fourth cup and one-half teaspoon soda added to compensate for the acidity of the honey. If the measuring cup is sprayed with nonstick cooking spray before adding honey, the viscous honey will drain quickly from the cup. The baking temperature should be reduced by 25F° (15C°).

Liquid honey should be stored at room temperature to retard crystallization; refrigerator storage causes crystals to start to form. Crystallized honey can be liquefied by placing the container in hot water or by microwaving very briefly just until the crystals disappear.

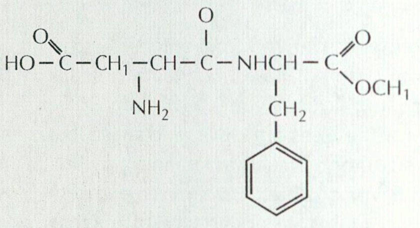
**Figure 9.4**
This beekeeper dons protective gear when he harvests honey from his beehives. Darios/Fotolia.

http://www.fda.gov/Food/default.htm —Information can be traced by searching for specific sugar substitutes.

## Other Sweeteners

Saccharin, which is not a carbohydrate, is a non-nutritive sweetener that has been used as a sweetener (Sweet'N Low®) by diabetics for years, but it also is chosen by some weight-conscious people in order to reduce their caloric intake. Saccharin is marketed in many commercial food products and in the granular and fluid forms for sweetening foods at home. Saccharin can be used in products, such as beverages, where sugar serves only a sweetening function, although some people find the aftertaste objectionable. Saccharin is not a suitable substitute for sugar in traditional candy recipes or batter and dough products where sugar performs other roles in addition to sweetening.

Other non-nutritive sweeteners are being developed and several are marketed today. Extensive tests on the safety of any proposed new additive, including sweeteners, must be completed and approved by the U.S. Food and Drug Administration before it can be used in any food. Cyclamates are available in some countries but not in the United States because some evidence of carcinogenicity was found in experimental animals fed unrealistically high doses of the sweetener. Aspartame (Equal, NutraSweet®) is a low-calorie sweetener approved for use in many different food products (Figure 9.5). This substance is a dipeptide composed of two amino acids, aspartic acid and phenylalanine, the latter being a concern for people with phenylketonuria. Because of its chemical composition, aspartame behaves like a protein and loses its sweetness when heated. A gram of aspartame will provide four kilocalories of energy, but the sweetness contribution is sometimes as great as 200 times that of sucrose. Since only small amounts of aspartame are needed, its use as a sweetener can reduce the calorie content of beverages and some other food items in which sucrose traditionally would be used.



Aspartame


**Figure 9.5**
NutraSweet® packages carry not only nutrition and ingredient information but also a statement that it contains phenylalanine and another that says it is safe for diabetics.
Ted Foxx/Alamy.

Neotame, also a sweetener, is another dipeptide. It has far greater sweetening ability than aspartame and has the added advantage that it does not yield phenylalanine as a breakdown product.

Sucralose (Splenda®) is a very sweet product (sucrose with three chlorines). This is being marketed for consumers to use in place of sugar in various applications, including baked products. Tagatose (Gaio®) is a sweetener derived from dairy products, which qualified it to be approved as GRAS (generally recognized as safe).

Acesulfame-K (Sweet One®, Sunette®), derived from acetoacetic acid, is being used widely because of its intense sweetness and suitability in a number of commercial food products. In 2008, the FDA approved the use of stevia, a very sweet compound from a plant native to Paraguay. Rebaudioside A (often referred to as Reb A) is the main compound in this no-calorie sweetener. It is being marketed currently as Truvia™. Isomalt (derived from sucrose) is used widely in food technology, but it is only about half as sweet as sucrose. Researchers are developing combinations of these various sweeteners in an effort to obtain optimum sweetening and performance characteristics in various sweetened food items.

*http://www.caloriecontrol.org/sweeteners-and-lite/sugar-substitutes*
—Summary information about several sweeteners.

## SWEETENING POWER

The sweetening power of pure sugars and of products containing sugars is of importance in formulating recipes, for the sweet taste of any food must please the diner's palate. People vary in their taste sensitivity, with some being able to detect sweetness at a far lower concentration than others can. One way of considering sugars as ingredients is to determine how sweet one sugar is in comparison with another. The sweetest sugars can be detected as being sweet at much lower concentrations than those that are only slightly sweet. Such tests ordinarily are conducted using dilute sugar solutions tested at room temperature.

## REACTIONS OF SUGARS

### Hydrolysis

Sucrose can undergo the severe chemical breakdown involved in caramelization, or it can be subjected to a milder change—that of hydrolysis. Hydrolysis of sucrose results in the formation of **invert sugar** (equal amounts of two simple sugars, glucose and fructose). This change, specifically called inversion, affects the sugar-containing products in which hydrolysis occurs because the usual end result is a mixture of sucrose and invert sugar, which together will crystallize less easily than will sucrose alone.

***invert sugar*** A mixture of equal amounts of glucose and fructose resulting from the hydrolysis of sucrose.

*http://www.nyu.edu/pages/mathmol/library/sugars/*
—Models of sugar structures.

***FOS*** Fructooligosaccharide, non-nutritive, sweet carbohydrate comprised of one molecule of sucrose and two or three fructose units.

***INDUSTRY INSIGHT***

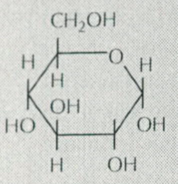
### FRUCTOOLIGOSACCHARIDES

Fructooligosaccharides (**FOS**) are sugars in which sucrose is joined with two or three fructose units, resulting in a somewhat more complex carbohydrate molecule that is not easily digested, but that does increase sweetness. These fructooligosaccharides are found naturally to a limited extent in bananas, tomatoes, onions, honey, and some other foods. Experiments in which Spiegel and co-workers (1994) added FOS to yogurt demonstrated that FOS was effective in improving the flavor and texture. The motivation for such research is the hope of obtaining highly palatable foods that appeal to consumers while also providing fewer calories. The fact that humans cannot digest FOS makes it possible to obtain a satisfactory yogurt without adding calories along with sweetness. FOS affords but one example of non-nutritive sweeteners and the search for low-calorie foods.

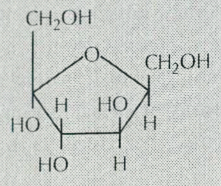
**SCIENCE NOTE**

## MONO- AND DISACCHARIDES

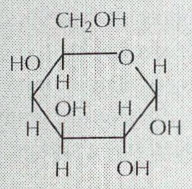
The sugars found naturally in foods are classified on the basis of the number of carbon atoms in their basic units and on the complexity of the total molecule. Some five-carbon sugars, called pentoses, are found in foods, but they have limited application in home food preparation. Ribose and arabinose are pentoses. Of more importance in food preparation are the hexoses, which are named because of their content of six carbon atoms. Glucose, fructose, and galactose are the three hexoses of particular interest. Their structures are shown below.



Glucose

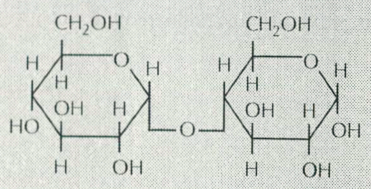


Fructose

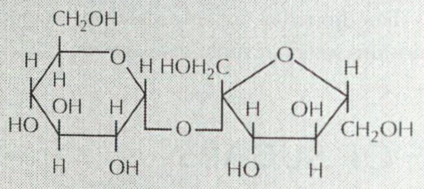


Galactose

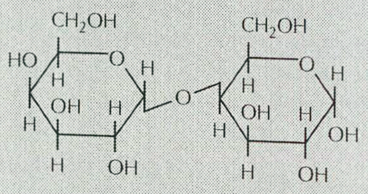
These three monosaccharides are used in the formation of three common disaccharides. Each molecule of a disaccharide is composed of two monosaccharides that have been united with the expulsion of a molecule of water. All three of the disaccharides of greatest importance in food contain one unit of glucose. In fact, maltose contains two units of glucose. Lactose contains galactose in addition to glucose, and fructose is the second monosaccharide in sucrose. Their structures are presented below.



Maltose



Sucrose



Lactose

Sucrose is the most common of the disaccharides and is used widely in food preparation. Lactose is the sugar in milk and sometimes is referred to as milk sugar.

***inversion*** Specific term for the hydrolysis of sucrose to glucose and fructose.

**Inversion** is promoted when sugar is cooked in a solution to which an acid has been added. In making crystalline candies, cream of tartar frequently is added as the acid ingredient to ensure that a moderate amount of invert sugar will be formed to help in achieving a smooth texture. A moderate to slow rate of cooking will result in an appreciable amount of inversion, while a fast rate of boiling a crystalline candy will permit less time for inversion to occur.

Some inversion is desirable when making crystalline candies because the presence of more than one sugar helps to inhibit crystal formation during the cooling period, thus aiding in creating a smooth-textured candy. However, excessive inversion presents a problem; too

**SCIENCE NOTE**

## CARAMELIZATION REACTIONS

When heated without water, sucrose crystals melt, and then chemical breakdown begins. First, the linkage between the fructose and glucose units of sucrose breaks. Continued heating then creates many different chemical compounds as a result of the breaking of the ring structure of both monosaccharides. Prominent among the compounds created by caramelization are organic acids. Evidence of the formation of these acids is seen when baking soda is added to caramelizing sugar; the alkaline ingredient combines with the acids to form carbon dioxide, causing the caramelized liquid to bubble and become porous. An application of this reaction to produce $CO_2$ is the making of peanut brittle, for this type of candy is heated to the point where caramelization is occurring, and then baking soda is added before the very viscous mixture has an opportunity to cool enough to become solid. The reaction of the soda with the organic acids in the candy causes the brittle to become opaque and porous as a result of the large amount of carbon dioxide generated.

much inversion of sucrose to glucose and fructose can interfere with crystal formation so much that the resulting candy will be too soft. The addition of a small amount of cream of tartar, combined with a moderate rate of heating, will provide the combination needed to produce an appropriately firm, smooth-textured crystalline candy.

Another means of causing hydrolysis is with the use of the enzyme **invertase**. Invertase is used commercially to catalyze the inversion of sucrose. As is true with any enzyme, invertase must not be heated if it is to retain its catalytic ability. Consequently, commercially produced chocolate creams are made by creating a fairly firm center filling that is mixed with invertase prior to dipping the chocolate. After a period of several days of storage, invertase will have inverted enough sucrose so that the filling softens to the desired consistency.

***invertase*** Enzyme mixed with fondant-type fillings to invert some of the sucrose and soften the consistency of commercial chocolates.

### Caramelization

Sucrose can be heated by itself until it becomes so hot that it melts and fairly rapidly goes from a colorless liquid to a golden brown and then to a deep brown, followed by black if heating is continued. At the same time that the color is changing, the aroma becomes caramel-like and eventually will smell like burning sugar unless cooled promptly. The temperature of caramelizing sugar is very high, and the chemical breakdown of the sugar proceeds so rapidly that boiling water usually is poured into the molten sugar at the desired stage to cool the mixture and halt caramelization. Even when the added water is boiling, there is a large temperature differential between the molten sugar and the boiling water, which results in some spattering briefly. This added water not only halts caramelization but also dilutes the sugar to make a caramelized sugar syrup for use in recipes. Otherwise, the undiluted sugar will solidify into a hard, brittle mass that cannot be incorporated with other ingredients.

*www.exploratorium.edu/cooking/candy/sugar*
—Science of making candy.

## TYPES OF CANDIES

Candy is called *khandi* in Arabic and sweets in England, but it has universal appeal regardless of the name. From the perspective of nutrition, candy certainly is not essential, but its popularity in various forms around the world indicates that candy likely is here to stay as a pleasure of life. The various candies are classified as crystalline or amorphous, depending upon their internal organization. **Crystalline candies** are the candies that can be bitten easily and can be cut with a knife. When viewed under a microscope, there are many areas in crystalline candies where organized crystal structure can be seen, along with some liquid. Fondant, fudge, panocha, divinity, and creams are examples of *crystalline candies*.

**Amorphous candies**, as the name implies, lack an organized structure. These candies generally have a higher concentration of sugar than the crystalline candies. Their cooked syrups

***crystalline candies*** Candies with an organized crystalline structure; easily bitten or cut with a knife.

***amorphous candies*** Candies with a very high concentration of sugar, making them too viscous to form an organized crystalline structure; texture ranges from chewy to very hard and brittle.

are so viscous that sugar crystals cannot form any type of organization. The amorphous candies, with their lack of organized crystal structure, are not chewed easily or cut with a knife. They range in texture from extremely chewy caramels to very hard or even brittle products, such as toffee.

Although crystalline and amorphous candies are both examples of sugar cookery, their preparation problems are unique. They both require careful cooking to the correct final temperature, but the problems associated with making crystalline candies are quite different from those involved in making high-quality amorphous candies.

## Crystalline Candies

The concentration of sugar in crystalline candies is appreciably lower than in the amorphous candies, which means that they are not boiled as long or to as high a temperature (Table 9.1). As a result, the likelihood of scorching and of obtaining an inaccurate temperature reading is reduced significantly. As with amorphous candies, however, a pan with even heating characteristics must be used. Since the temperature of boiling candies reflects the sugar concentration, very accurate temperature control is vital to obtaining the correct firmness of crystalline candies. A small error on the low side will cause the candy to be too soft, and a degree or two above the correct temperature will create a crumbly, hard product.

Two other factors, in addition to the final temperature reached, influence the firmness of a crystalline candy. One is the rate of heating. If a candy is heated unusually slowly, the amount of inversion that occurs will be excessive. The large proportion of the resulting glucose and fructose will interfere more than normally in the crystallization process, and the candy will be a little softer than the final temperature would suggest. This problem can be avoided by being sure to use a pan large enough to allow the boiling candy to boil vigorously without splashing over the top.

The second factor that might cause a crystalline candy to be too soft relates to making candy on a rainy day. This is not an old wives' tale; there is scientific evidence to support the result. Sugar is very **hygroscopic**—that is, it attracts or absorbs water readily; this is particularly true when it is in a hot solution. Thus, while crystalline candies are cooling in an extremely humid environment, moisture will be removed from the air and held in the cooling candy. The result is that the candy will have higher moisture content after standing than it did when it was first removed from the heat.

***hygroscopic*** Attracting (or absorbing) water.

In crystalline candies, the moisture level is so critical to the firmness of the candy that this small amount of absorbed moisture will make the candy just a bit too soft. To compensate for this, on a rainy day crystalline candies should be cooked about one degree Fahrenheit higher than the recipe states. This adjustment is unnecessary for amorphous candies because their moisture level is slightly less critical.

**TABLE 9.1**
**INGREDIENTS AND FINAL TEMPERATURES FOR SOME TYPICAL CANDIES**

| Candy | Basic Ingredients | Final Temperature °F (°C) |
|---|---|---|
| *Crystalline* | | |
| Fondant | Granulated sugar, corn syrup or cream of tartar, water | 238 (114) |
| Fudge | Granulated sugar, cocoa or chocolate, milk, corn syrup, butter | 234 (112) |
| Panocha | Brown sugar, granulated sugar, milk, corn syrup, butter | 234 (112) |
| *Amorphous* | | |
| Caramels | Granulated sugar, corn syrup, butter, cream | 245 (118) |
| Taffy | Granulated sugar, corn syrup, water | 260 (127) |
| Toffee | Granulated sugar, butter, water, corn syrup | 300 (149) |

In addition to the firmness, crystalline candies are evaluated on their smoothness. Ideally, a crystalline candy will feel perfectly smooth when rubbed with the tongue against the roof of the mouth. There should be no suggestion of grittiness or rough crystals even though these candies are defined as having an organized crystalline structure. For success, the crystals must be very small, rather than in large aggregates, for it is these large clumps of crystals that feel rough on the tongue.

There are three factors of particular importance in achieving a very smooth, velvety texture: (1) interfering agents, (2) adequate beating, and (3) rapid crystallization.

**Interfering agents** are ingredients or components that make it difficult for sugar crystals to form and clump together in large aggregates. Butter and the fat in chocolate are examples of interfering agents in fudge because they help to keep sugar crystals from bonding tightly to each other. The use of corn syrup is another; its viscous quality and the presence of a mixture of sugars (maltose and glucose) are useful in blocking crystals from aggregating. Increased viscosity makes it more difficult for sugar crystals to align closely enough to hydrogen bond to each other, and the different shapes of maltose and glucose molecules also help to prevent bonding between crystals. Cream of tartar and other acidic ingredients interfere indirectly by promoting the inversion of sucrose to give a mixture of sugars.

***interfering agents*** Butter, corn syrup, or other ingredient inhibiting crystal formation.

***heat of crystallization*** Heat energy released when a viscous sugar solution crystallizes and forms a solid mass.

Beating is an important part of preparing high-quality crystalline candies. By beating these candies continuously from the time crystallization is starting, the sugar crystals are kept in motion and are not able to bond together into coarse aggregates. To achieve the desired very smooth crystalline candy texture, it is necessary to continue beating from the time crystallization begins until the candy softens slightly just before becoming firm. However, even diligent and vigorous beating cannot prevent a slight amount of graininess if crystallization begins too early in the cooling process.

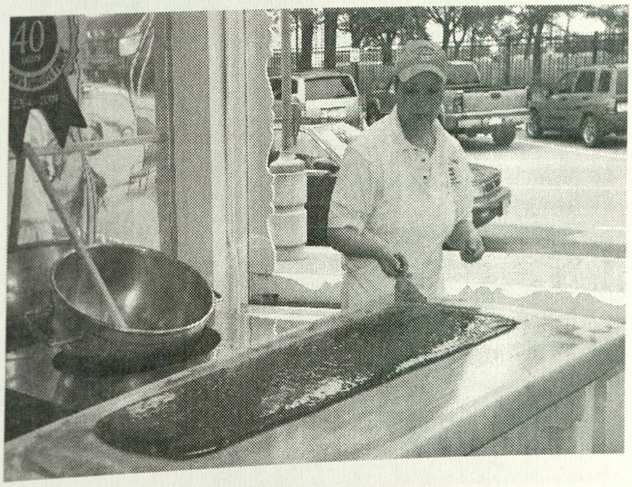
Beating does not cause the candy to get hard; it simply influences how readily the crystals grow together. It also modifies the color by trapping air throughout the solidifying, crystallizing candy. The combination of the air and the numerous sugar crystals produces an opaque, white or lighter-colored candy than would result if beating were omitted.

The last factor influencing the smoothness of crystalline candies is the point when crystallization begins. If crystals are formed very rapidly, the candy will become locked into a fine crystalline structure that will change very little over time. The fine crystals remain separated; they do not rearrange into large aggregates if the total crystallization process can occur within an extremely brief period of time. This circumstance occurs when all of the sugar in a crystalline candy is dissolved during the boiling period and the candy is allowed to cool to about 110°F (43°C) without any disturbance. If beating is initiated at this point, there will be extremely rapid formation of many sugar crystals and little opportunity for crystals to clump and create a grainy texture.

***mother liquor*** Saturated sugar solution between the crystals in crystalline candies.

When beating crystalline candies, it may be difficult at first to spot the exact point when beating should be stopped and the candy should be spread in preparation for cutting into pieces. The clue to the stopping point is the very slight softening of the candy due to the **heat of crystallization** (heat energy released when the very viscous sugar solution changes into crystals). With experience, this softening can be detected, but it is difficult to see in small batches of candy because the heat is dissipated so rapidly. If the candy is not spread in time, the crumbly mass can be kneaded gently into a cohesive, attractive candy and shaped to the desired thickness (Figure 9.6).

***Figure 9.6*** Crystalline candies soften slightly (due to the heat of crystallization) just before they solidify; this is the critical time to spread them quickly and thus avoid kneading. David R. Frazier Photolibrary, Inc./Alamy.



Sometimes crystalline candies do not meet expectations. Perhaps they are too hard or too soft, or maybe they have a gritty texture. Unlike a number of food products, such candies can be salvaged. Water needs to be added to the candy in a pan, and then the dissolved candy should be reheated until the correct final temperature is reached. The cooling and beating are done the same as they would be done for any crystalline candy.

When a high-quality crystalline candy has been prepared, it will improve even more by undergoing a 24-hour ripening period in a tightly covered container. During this period, there will be a slight softening and an increase in smoothness. However, longer storage will allow small crystals to dissolve in the **mother liquor** and recrystallize on larger

***saturated solution*** Homogeneous mixture that has as much solute in solution as possible at that temperature.

***supersaturated solution*** Solution in which more solute is dissolved than theoretically can be dissolved; created by boiling a true solution to a high temperature and then cooling it very carefully.

***co-crystallization*** Addition of gum or other ingredient to a highly concentrated sugar solution just before beating very fast, a process that traps the second substance in a mass of microcrystals.

crystal aggregates. The mother liquor is the saturated sugar solution found between the sugar crystals throughout the candy. This liquid helps to soften a crumbly, overbeaten candy into a workable mass during kneading. Since the smallest sugar crystals in a candy are the ones most susceptible to being dissolved in the saturated mother liquor, crystalline candies gradually become grainy during prolonged storage.

## Amorphous Candies

During the cooking of amorphous candies, water is evaporated until the correct concentration of sugar has been achieved. This is determined by the temperature of the boiling candy, which ranges from about 260° to 300°F (127°–149°C), depending upon the type of amorphous candy being prepared. As water is being evaporated, the sugar concentration is effectively increasing, with the result that the boiling point of the solution keeps rising. The effects of sugar on vapor pressure and the temperature of boiling are discussed in Chapter 4.

These candies become extremely viscous in the later stage of cooking, making it difficult to keep the candy in total contact with the thermometer. If air is trapped around the bulb, the reading will be inaccurately low, and overcooking to the point of scorching may occur. Scorching may also be a problem if amorphous candies are boiled in pans that heat unevenly; a heavy aluminum pan with a perfectly flat bottom provides uniform heat distribution to avoid possible burning of any portion of the candy. Careful stirring during the

### SCIENCE NOTE
### SATURATED AND SUPERSATURATED SOLUTIONS

In sugar cookery, sugar is a solute that is dissolved in a solvent (water or milk usually) to make a true solution. This is a true solution because it is homogeneous; that is, the content of samples taken from different portions of the mixture will all be the same. The ability of water to dissolve sugar varies with the temperature of the solution. This is quite apparent when making candy. At first, the solution is gritty no matter how much it is stirred because much of the sugar cannot be dissolved until the temperature rises. Gradually, the sugar all goes into solution, and the temperature of the boiling mixture starts to rise. This is now a **saturated solution**, which means that no more sugar can be dissolved in that amount of water at that temperature. However, the percentage of sugar in solution continues to rise in the boiling candy as the temperature rises and water evaporates. Throughout this boiling and evaporation period, the candy is a saturated solution, although the percentage of sugar in solution continues to increase until the final temperature is reached and the candy is removed from the heat.

Once the candy has been removed from the heat, the solution will begin to cool. This may seem to be perfectly natural, but in candy cookery, the cooling needs to be considered in relation to the sugar in the solution. Remember that less sugar should be in solution at a cooler temperature than could be dissolved in a saturated solution at the higher temperature reached during cooking. In other words, more sugar has been placed in solution by going to the higher final temperature than theoretically can be in solution as the candy cools. And yet, it is possible to keep this extra sugar in solution for quite a long time during the cooling period. By this careful cooling, a **supersaturated solution** is created, which means that more sugar is in solution than theoretically can be in solution at that temperature. The cooler the candy gets, the less stable the supersaturated solution becomes because less and less sugar can be dissolved as the temperature drops. Ideally, a highly supersaturated state will be created.

If some nucleus is introduced into a supersaturated solution, the excess sugar in solution begins to crystallize and precipitate. The presence of a crystal of sugar, a piece of lint, or any other object can serve as the starting point for crystals of sugar to form. If this occurs when the candy has cooled only a little, there will be rapid crystallization of the small amount of dissolved sugar that should not have been in solution. Gradually, as the candy continues to cool, the extra sugar will continue to crystallize, adhering to the existing crystalline nucleus and creating a gritty texture even if beating is done continuously from the time the crystals start to form until the candy becomes solid.

In the ideal circumstance, a crystalline candy will cool to 110°F (43°C) before any crystals form, a condition creating an extremely unstable situation. If beating is started at this point, the large excess of dissolved sugar will start to crystallize almost simultaneously, and the candy will become a solid mass within a matter of a very few minutes. Crystal aggregates simply cannot grow large under this circumstance if beating is vigorous until the candy solidifies. This is the reason that careful cooling to create a highly supersaturated solution is so important to success in making smooth crystalline candies.

During the manufacturing of granulated sugar, it is possible to trigger instantaneous formation of crystals from a pure, highly concentrated sugar solution with extremely rapid beating; this procedure is called spontaneous crystallization. The result is extremely minuscule crystals. A second component (a gum or oil, for example) can be stirred with the sugar solution just prior to crystallization. The tiny sugar crystals entrap this second ingredient uniformly and promote a very smooth texture. This process is referred to as **co-crystallization**.

### JUDGING POINTS
## CRYSTALLINE CANDIES

- Velvety smooth texture
- Firm, but easily cut or bitten without crumbling
- Pleasing flavor with no suggestion of scorching

entire boiling period is an additional aid in making high-quality amorphous candies.

Amorphous candies are evaluated on the basis of their texture and flavor, characteristics that vary with the specific type of candy. Caramels should be wonderfully chewy, while taffy (Figure 9.7) can be pulled while cooling, but ordinarily is a bit too hard to bite once it cools; toffees and brittles break easily when hit with a knife handle. A particular amorphous candy is judged on whether or not it fits the expected chewiness or hardness for the specific candy being made. The flavor should not have any trace of scorching or burning and should be pleasingly rich and characteristic of the ingredients and flavorings used.

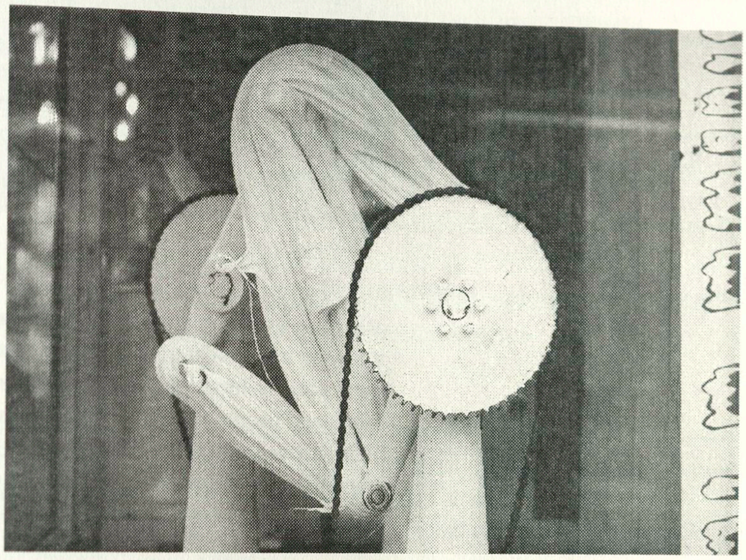


*Figure 9.7*
Saltwater taffy is being pulled by machines that not only achieves the desired texture for the candy but also attracts customers to eat it. Dennis MacDonald/Alamy.

Commercially, candies are divided into three categories, according to their ingredients:

1. Candies made entirely of sugar with or without flavor and color (hard candies, creams, stick candies).
2. Candies containing at least 95 percent sugar and a maximum of 5 percent non-sugar ingredients (pectin jellies, marshmallows, nougats).
3. Candies with a minimum of 75 percent sugar, and between 5 and 25 percent non-sugar ingredients (fudge, caramels, starch jellies, chocolates).

The problems encountered in commercial confectionery are a composite of the problems encountered in making homemade candies, plus storage and shipping hazards. Some of these problems can be alleviated by the use of appropriate additives. For instance, glycerol and large quantities of corn syrup are helpful in maintaining moisture in candy and in retarding the development of a gritty texture in creams and mints. Various emulsifiers, including monoglycerides, are helpful in retarding staling and toughening of candies having a starch-gelled base.

Inversion to promote a mixture of sugars and a smooth crystalline candy is aided by adding cream of tartar in commercial candies. Invertase is a vital additive in softening cream centers after chocolates have been dipped.

### JUDGING POINTS
## AMORPHOUS CANDIES

- Appropriate texture for type (caramels: chewy; taffy: hard; brittles and toffee: crunchy, easily broken)
- Pleasing golden brown color for caramels, brittles, and toffee; light color for taffy
- Full flavor, with no hint of scorching or burning

### CULTURAL ACCENT
### TURKISH DELIGHT

Turkish delight, a national favorite of that country, is a unique gelatinous candy that many feel definitely deserves its name. Apparently this candy (also known as lokum) was developed for one of the Ottoman sultans because the sultan wanted a confection to delight wives in the harem. The chef tried many combinations of ingredients until he finally combined cornstarch with a gum (probably gum arabic), sugar, rose water, and various nuts. The result was an overwhelming success, and it continues to be a favorite in Turkey.

This candy has a gummy mouthfeel and is only moderately sweet, although it usually is coated lightly with confectioner's sugar. Rose water, a familiar aromatic ingredient in Middle Eastern cookery, provides a delicate, flowery flavor in the candy. Pistachios are ubiquitous in Turkey, so it is not surprising that Turkish delight made with pistachios is the favorite type of lokum.

For candies that are gels (orange slices, for example), gums are essential to form the gel. Most gums used in candy production are carbohydrates derived from seaweed, plant seeds, or tree exudates. The seaweed extracts, such as agar and Irish moss, have been used commercially for a long time, but often now are replaced in commercial candy-making by starch and pectin. Carrageenan (Irish moss) is used to prevent the "oiling off" that occurs in high-fat candies such as caramels, toffees, and nougats in hot weather. Two tree exudates, gum arabic and gum tragacanth, have the dual functions of preventing crystal growth and emulsifying fat to avoid fat separation in candies.

## SUMMARY

Carbohydrates are important sources of energy in the diet, whether in the form of various sugars or starch; other complex carbohydrates are valued as roughage. In food preparation, the simple carbohydrates, the sugars, are used as sweeteners to add to the pleasure of eating. The word *carbohydrate* is etymologically derived from the fact that, chemically, all compounds in this class are hydrates of carbon.

Among the many sweeteners available to consumers today, the various types of cane and beet sugars are used in by far the greatest quantity, with granulated sugar being the most common form selected. Dessert sugar and powdered or confectioner's sugar are other refined sweeteners, the latter having cornstarch added to it to keep the fine powder from lumping. Raw sugar, a partially refined sugar, is nutritionally comparable to refined sugar and is more expensive. Light and dark brown sugars contain impurities that alter their color and flavor. Maple syrup and sugar have unique flavors attributable to the impurities in the maple sap from which they are made. Molasses is another distinctive sweetener and is the by-product, either sulfured or unsulfured, resulting from the processing of cane sugar.

Corn syrup is made from cornstarch by hydrolysis. A variation produced from corn syrup is high-fructose corn syrup, the result of the action of isomerase (an enzyme) on the sugars in corn syrup. Honey also is a fluid sweetener, this one being naturally high in fructose. The distinctive flavor of honey varies with the source of the nectar the bees collect, but all types result in very rapid browning in baked products.

Saccharin is a non-nutritive sweetener used by many to avoid calories from sugar and by diabetics as a means of limiting sugar intake. The bitter aftertaste is objectionable to some people. Aspartame, a dipeptide, is a low-calorie sweetener. Its intense sweetness means only small amounts of aspartame are needed to sweeten a beverage or other food item.

Sucralose (Splenda®) is a sweetener derived from dairy products, which qualified it to be approved as GRAS (generally recognized as safe). Acesulfame-K (Sweet One®, Sunette®), Tagatose (Gaio®), and FOS are other sweeteners.

Sugars are classified as monosaccharides and disaccharides, with the disaccharides being made up of two units of the monosaccharides. Glucose, fructose, and galactose (all hexoses) are the common monosaccharides; these are combined in various ways to form sucrose (table sugar), maltose, and lactose (milk sugar).

Sucrose, the sugar commonly used in cookery for sweetening, tenderizing, browning of baked products, and other purposes, undergoes a severe chemical breakdown when it is heated to very high temperatures. This process, called caramelization, results in the formation of many different compounds, including organic acids. Hydrolysis is a less severe reaction and results in the formation of an equal mixture of two sugars (glucose and fructose); the mixture is called invert sugar.

The two types of candies are crystalline and amorphous, the difference being that crystalline candies have organized crystals

of sugar throughout, while amorphous candies are completely disorganized and range from chewy to very hard. The type of candy, whether crystalline or amorphous, is determined in large measure by the final cooking temperature; crystalline candies are cooked to lower temperatures than amorphous candies. The lower temperature of crystalline candies means that the concentration of sugar is somewhat lower, a difference that enables the sugar crystals to form an organized network in the cooling, fairly viscous crystalline candies.

Amorphous candies should be the correct texture for the type of candy (ranging from chewy caramels to brittle toffees) and should not have any trace of scorching, the most common problem in their preparation. In contrast, crystalline candies are evaluated on the basis of being firm yet soft enough to bite easily and having a velvety smooth texture. This texture is the result of achieving a highly supersaturated solution and then beating adequately until the structure sets. Commercial candies are categorized according to the percentage of sugar they contain. Many of these have various additives to enhance the quality of the candy when it reaches consumers.

## STUDY QUESTIONS

1. What is the result of a very slow rate of heating on a crystalline candy? Explain the reaction that occurs.
2. What influence does the amount of beating have on a crystalline candy?
3. Does the time of initiation of beating influence the quality of a crystalline candy? Explain.
4. Explain the purpose and action when each of the following ingredients is added to a basic fondant recipe: cream of tartar, corn syrup, chocolate, butter. Explain the action of each.
5. Why does the temperature of boiling candy rise gradually?

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