Sugar: The Simplest of Carbohydrates

Honey has been used as a source of simple carbohydrates in food preparation for thousands of years.

Objectives

After studying this chapter, you will be able to:

- **summarize** how carbohydrates are produced through the process of photosynthesis.
- **identify** the monosaccharides that are combined to form each of the disaccharides.
- **explain** the chemical process of hydrolysis.
- **name** types of sugar used as food ingredients.
- **list** the functions of sugar in food preparation.
- **evaluate** the role of sugar in a nutritious diet.

Key Terms

- carbohydrate
- photosynthesis
- saccharide
- hydroxyl group
- monosaccharide
- fructose
- glucose
- mannose
- galactose
- ribose
- ribonucleic acid (RNA)
- disaccharide
- sucrose
- maltose
- lactose
- hydrolysis
- invert sugar
- alcohol
- molasses
- dextrose
- solubility
- supersaturated
- interfering agent
- agitation
- ripening
- caramelization
- glycogen
- diabetes mellitus
- insulin
Scientists estimate that more than 50% of the earth’s biomass is made up of carbohydrate compounds. (Biomass refers to the dry weight of all plants and animals.) About 75% of the dry mass of all land plants and seaweed are carbohydrates of some form. This includes the plants used to make such products as wood, paper, cotton, linen, and rayon.

Because of their abundance throughout nature, carbohydrates make up the bulk of the biomass in food. Carbohydrates are a major source of energy for humans, providing 55% to 80% of calorie needs. Compared with people in other countries, people in the United States have one of the lowest carbohydrate intakes. Even so, these organic compounds still provide the bulk of energy in the U.S. diet. See 8-1.

Carbohydrates provide a reserve energy store for all living things as well as forming the vital structure of living cells. Even DNA, which provides genetic information to all living things, is composed of a carbohydrate base.

Understanding the functions of carbohydrates is important to many areas of industry and research. However, it is vital to food science. You will rarely work with a food mixture that does not contain carbohydrates in some form.

You can group carbohydrates in food ingredients into three categories: sugars, starches, and fiber. In this chapter, you will examine the structures and functions of sugars. In Chapter 9, you will learn about starches and fiber.

**Carbohydrate Production**

All carbohydrates are compounds composed of the elements carbon, oxygen, and hydrogen. The name carbohydrate means a hydrate of carbon, or carbon that is loosely bound with water. This is because scientists originally felt the molecular structure was \( \text{C}_6(\text{H}_2\text{O})_6 \). Although they quickly abandoned this view, the name carbohydrate has remained.

Carbohydrates are nature’s means of storing solar energy. Through the process of photosynthesis, plants convert energy from the sun into the most common of the carbohydrates, glucose. Photosynthesis requires carbon dioxide, water, chlorophyll, and sunlight. Sunlight is the source of energy that powers the chemical reaction of photosynthesis. Chlorophyll is a green pigment found only in plants. It traps the radiant energy from the sun and turns it into chemical energy. All green plants use this process for growth as well as energy storage. The equation for photosynthesis is

\[
6\text{CO}_2 + 6\text{H}_2\text{O} + \text{sunlight} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2
\]

Initially, all carbohydrates are produced in the form of glucose. Plants can then convert glucose into whatever form of sugar, starch, or fiber they need at the time.

As the plant matures, it makes glucose into fiber to form the structure of the stems and leaves. As the plant reaches full size, it begins to transfer its energy into sugars and starches. These are storage forms of energy the plant uses for reproduction. As the seeds develop, the carbohydrates start mostly as sugars. Then they gradually change into more

---

8-1 Most calories on the average plate and in the average diet should come from carbohydrate sources, such as pasta and vegetables.
complex starches. This is why baby corn and petite peas are sweeter than their full-sized counterparts. See 8-2.

**Sugars**

The simplest types of the carbohydrates are called sugars. In organic chemistry, the name saccharide has been given to all carbohydrates classified as sugars. Sugar was the common name used before organic chemists developed the naming system presently used to identify organic compounds.

**Structure**

Sugars are organic compounds. That simply means sugars contain carbon compounds. All living organisms are composed of organic, or carbon-based, compounds.

Organic compounds are grouped by their structure. For example, all carbohydrates contain hydroxyl groups. A hydroxyl group is an oxygen atom and a hydrogen atom bonded together. A hydroxyl group is represented by the chemical symbol -OH. As you know, oxygen atoms prefer to bond with two atoms. The second oxygen bond in a hydroxyl group is formed with a carbon atom, as represented in the following diagrams:

```
     |  O  |
   -C--OH  or  -C--O-H
     |     |
```

**Monosaccharides**

A simple sugar is a molecule that cannot be broken down into a smaller molecule without changing its basic nature. The simple sugars are known as monosaccharides, or sugars that contain one basic molecule.

Examples of monosaccharides found widely in food products are fructose, glucose, galactose, and mannose. In organic chemistry, the names of saccharides end in -ose. Fructose is a monosaccharide found widely in fruits and honey. Glucose is the most abundant of the sugars, and it is people's basic energy source. It occurs naturally in blood, grapes, and corn, 8-3. The body converts all sugars and starches into glucose before using the glucose for energy. Mannose is found in eggs and

![8-2 Tender, young kernels of corn are sweeter than mature kernels because they contain a higher percentage of sugars.](image1)

![8-3 Glucose is one of the sugars found in grapes.](image2)
some plants and usually occurs as a component of long chains of sugars. Galactose can only be found in animals and humans and is one of the basic sugars found in milk. All these sugars have six carbon atoms, twelve hydrogen atoms, and six oxygen atoms.

Originally, scientists believed sugar molecules existed primarily in a linear form. The carbon atoms were thought to form a line. The hydrogen and oxygen atoms were believed to branch off the carbon atoms at different angles.

Scientists now know most simple sugars in nature have a central ring structure. Constructing three-dimensional models of sugars can give you a better idea of how the atoms align with each other. Fructose has a five-member ring. Glucose, mannose, and galactose have six-member rings.

When scientists create diagrams of any ring-shaped organic compound, they simplify the drawing. They use the junction of lines to represent the location of a carbon atom. They draw lines where hydrogen atoms are located, but they do not write the letter H. In the following example, the diagram on the left shows glucose as a ring with all the atoms represented by letters. The diagram on the right is the shorthand version of the same molecule.

All monosaccharides occur most frequently in a ring structure that contains five carbon atoms and one oxygen atom. They differ in the way the hydrogen and oxygen atoms are arranged around the ring. The difference in position affects the characteristics of the sugar and how it will respond in food preparation.

To understand the importance of the arrangement of the atoms, look at two basic forms of glucose: α-D-glucose and β-D-glucose. As you can see from the following diagram, the alpha (α) glucose and beta (β) glucose have only one difference. That is the position of the -OH group on the right side of the ring. This one change in position determines whether the body is able to digest the sugar. Alpha-glucose is the basic energy source for humans. Beta-glucose is the main component of dietary fiber that provides bulk for the digestive track. However, it provides no nutritive value because people cannot digest it.

So far, the simple sugars described have a basic formula of C₆H₁₂O₆. There are also some sugars that contain only five carbon atoms. These are riboses. The body uses them as the basic building blocks for ribonucleic acid (RNA). RNA carries the genetic code in the cells and is used for the production of DNA.

Disaccharides

Sugars found in nature do not normally occur as monosaccharides. The sugar molecule's structure enables it to readily combine with other sugars to form chains. A disaccharide is two joined monosaccharides. Most sugars consumed in the world are disaccharides. Sucrose, or table sugar, is a disaccharide that contains one glucose molecule and one fructose molecule. Other disaccharides found in the food supply are maltose and lactose. Maltose is commonly found in malted grains. It is made of two glucose molecules. This disaccharide is the least sweet. When in powder form, it is tan rather than clear or white like sucrose. Lactose is the sugar found in milk. It is composed of one glucose molecule and one galactose molecule. In pure form, it is white and contributes some of the color you associate with milk.

When two monosaccharides join, a hydroxyl group from one and a hydrogen atom from the other separate to form water. See 8-4.
This process of molecules joining and releasing water is reversible. Hydrolysis occurs when a large molecule, such as sugar, is divided into smaller parts by adding water. If you hydrolyze a molecule of sucrose, you will get one molecule of fructose and one molecule of glucose. The body uses this hydrolysis process to digest the disaccharides in food. For hydrolysis to occur, water must be present. This is why sweetened drinks are not as thirst quenching as plain water. Part of the water is used to digest the sugar and is not available for other functions.

Three conditions can trigger hydrolysis. One condition is the presence of an enzyme to set off the reaction. A second condition is the addition of an acid. A third condition is the addition of heat. Digestion of sugar involves the addition of the enzyme sucrase. This enzyme is present in saliva. Thorough chewing of your food enables the enzyme to be mixed into the food so the enzyme can work quickly. Lactose-free milk is produced by adding an enzyme to hydrolyze the sugar.

Each type of sugar requires a different enzyme for hydrolysis to occur. You can determine the names of the enzymes by simply changing the -ose ending of the sugar to -ase. For instance, sucrase hydrolyzes sucrose and lactase hydrolyzes lactose. Sucrase is also known as invertase. This is because the fructose and glucose mixture that results from the hydrolysis of sucrose is sometimes called invert sugar.

### Alcohols

All organic compounds that contain at least one -OH group are called alcohols. Sugars are a related group of compounds that have multiple -OH groups plus an oxygen atom with a double bond. This similarity in chemical structure helps explain the high caloric content of most alcoholic (ethanol) beverages.
Lactose-reduced dairy products can be digested easily by people who experience lactose intolerance.

Lactase is an enzyme that is present in the small intestines. Its presence is necessary for the digestion of milk sugar. Lactose intolerance is an inherited inability to produce the lactase enzyme necessary to properly digest lactose or milk sugar. Most Asian, Native American, and African American adults experience this problem to some degree.

Symptoms of lactose intolerance include a sour aftertaste when drinking milk. Gas, bloating, nausea, diarrhea, and flu-like stomach cramps followed by constipation are other symptoms.

People can buy lactase from most pharmacies in either pill or liquid form. Experimentation with dosages will help people determine how much of the enzyme they need to avoid symptoms when consuming milk products. The liquid lactase is usually added to milk and allowed to sit before drinking. The lactase will cause the milk to have a sweeter flavor. This is because the lactose has been broken down into glucose and galactose.

Dairy producers have developed a variety of lactose-free and lactose-reduced products. Examine the labels in the dairy case. Many stores stock milk that has 70% to 100% of the lactose removed. Some gourmet ice cream manufacturers are also making lactose-reduced ice creams.

Lactase is produced by Lactobacillus acidophilus bacteria, which normally live in the intestines. Antibiotics will kill these helpful bacteria as well as the bacteria that cause infections. Therefore, milk will sometimes be difficult to digest for several weeks after taking antibiotics. You can take care of this problem by eating a serving of yogurt shortly after finishing your antibiotic prescription. Be sure to choose yogurt that contains an active culture of Lactobacillus acidophilus.

Names of alcohols end in -ol. Examples include ethanol (ethyl alcohol), methanol (wood alcohol), and isopropanol (rubbing alcohol). All these alcohols are toxic if consumed in excess. Ethanol is the alcohol in alcoholic beverages. It can be made from any sugar or starch source. Small amounts of methanol in bad batches of "moonshine" have been known to cause permanent nerve damage, blindness, or death. Methanol is produced by burning wood without oxygen present. Isopropanol is derived from petroleum and is not safe to consume.

There are several commonly used additives that are "sweet" alcohols. These alcohols are glycerol, mannitol, sorbitol, and xylitol. One source of glycerol is animal fats. See 8-5.
The Sweet Alcohols

<table>
<thead>
<tr>
<th></th>
<th>Glycerol</th>
<th>Mannitol</th>
<th>Sorbitol</th>
<th>Xylitol</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure</strong></td>
<td>CH₂OH</td>
<td>CH₂OH</td>
<td>CH₂OH</td>
<td>CH₂OH</td>
</tr>
<tr>
<td></td>
<td>H-C-OH</td>
<td>HO-C-H</td>
<td>HO-C-H</td>
<td>H-C-OH</td>
</tr>
<tr>
<td></td>
<td>CH₂OH</td>
<td>HO-C-H</td>
<td>HO-C-H</td>
<td>HO-C-H</td>
</tr>
<tr>
<td></td>
<td>H-C-OH</td>
<td>H-C-OH</td>
<td>H-C-OH</td>
<td>CH₂OH</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Sources</strong></th>
<th>Exists in wine and beer</th>
<th>Extracted from seaweed</th>
<th>Fruits: apples, berries, pears, plums, seaweed and algae</th>
<th>Apples, berries, plums, and other foods</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>Warm, sweet, oily liquid</td>
<td>Sweet, white, odorless crystalline solid</td>
<td>Sweet, white powder, flakes, or granules</td>
<td>Sweet, white, granules</td>
</tr>
<tr>
<td><strong>Calories/gram</strong></td>
<td>2.0</td>
<td>1.6</td>
<td>2.6</td>
<td>2.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Uses</strong></th>
<th>Humectant¹ in candy Solvent for colors and flavors Used in beverages, baked goods, gelatin, chewing gum, meat products, and commercial hot fudge sauces</th>
<th>Texturizer² in gum and candy Sweetener in sugar-free products but does contain calories and carbohydrates</th>
<th>Texturizer, humectant, anticaking agent³, diabetic sugar substitute</th>
<th>Texturizer, humectant, sugar substitute Can be used in baking</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th><strong>Cautions</strong></th>
<th>No limitations</th>
<th>May worsen kidney disease</th>
<th>Excess consumption may cause diarrhea</th>
<th>Excess consumption may cause diarrhea</th>
</tr>
</thead>
</table>

¹Humectants are additives that help products retain or hold onto moisture.
²Texturizers are additives that give food products a desired mouth feel.
³Anticaking agents are additives that keep powders or granules from lumping.

8-5 The sweet alcohols are used as additives to serve a variety of functions in food products.

Sources of Sugar

Sugars have a sweet flavor and provide 4 calories of energy per gram. Types of sugars commonly used as food ingredients are granulated, brown, and confectioner’s sugars; honey; corn syrup; molasses; and maple syrup. Food companies often use several kinds of sweeteners in a single food product. This allows food scientists to optimize sweetness for each product and minimize product costs.

Each sweetener is listed separately in the ingredient list on product labels. Total carbohydrates are listed on the Nutrition Facts panel on a food label. Amounts of dietary fiber and sugars are identified under the figure for total carbohydrates. You can learn to recognize the names of sugars that may appear on food labels. This will help you be aware of the sugar content of products you consume. See 8-6.

Most sweeteners used today are extracted from plants that are high in sugar content.
8-6 Reading Nutrition Facts panels and ingredient lists can help you become aware of the sugar content of food products.

Sweet syrups are extracted, the impurities are removed, and all or part of the water is removed. Sources of these sugars are sugar cane, sugar beets, maple trees, corn, and sorghum. One type of sweetener, honey, is manufactured by bees rather than being extracted from plants.

Sugar Cane

The Chinese were the first to discover the high concentration of sugar in sugar cane plants. They developed a process to extract sugar syrup from the cane.

The crude, boiled liquid pressed from sugar cane is known as molasses. The composition of molasses will vary with its degree of refinement. It contains 35% to 50% sucrose and 15% to 20% invert sugar. Molasses is 20% to 25% water and has a 2% to 5% mineral content. Popular foods containing large amounts of molasses are gingerbread cake, gingersnap cookies, and shoofly pie.

Brown sugar is cane sugar that has not been completely refined. Brown sugar is 85% to 92% sucrose. The brown color and characteristic flavor are due to the substances in sugar cane that form molasses when extracted. It is the molasses that gives brown sugar its moist texture and distinctive flavor. Brown sugar is used in baking where the additional coloring and flavor are desirable.

Brown sugar must be stored in a sealed container to prevent loss of moisture. Brown sugar that is left open will become hard and crumbly. The moist texture can be regained by adding apple slices or a slice of fresh bread to the container. In time, the sugar will absorb enough moisture from the bread or apple to make the brown sugar moist again.

With further processing, all minerals, flavorings, and coloring agents can be removed from brown sugar. This leaves only the crystalline substance you know as granulated sugar. The size of sugar crystals can be altered by grinding. Confectioner’s sugar is granulated sugar that has been ground into a fine powder. Most confectioner’s sugar has cornstarch added to help prevent caking during storage.

The number of Xs on the label of confectioner’s sugar refers to how finely the sugar has been ground. The most common types are 4X, 6X, and 10X. The larger the number is, the finer the powder will be. Finer powdered sugars produce candies and icings with smoother textures. Type 4X sugar is used in the manufacture of cough drops and chewing gum. It is also the sugar of choice for marshmallows and chocolates. Type 6X sugar is used for cream
fillings, uncooked fondants, and icings. It is also sprinkled on buns, pies, and pastries. Ultrafine, 10X, powdered sugar is used for the finest icings and fondant fillings.

Sugar Beets

Sucrose is also found in sugar beets. There is no difference in the performance of beet sugar and cane sugar. There is, however, usually a difference in cost. Sugar beets can be more economical to grow and process. See 8-7.

Health Tip
The source of granulated sugar is only important to a person who is allergic to the original plant source. Someone who is highly sensitive to beets may experience problems from consuming beet sugar due to plant residues in the sugar. Likewise, someone who is highly sensitive to sugar cane may experience problems from consuming cane sugar.

Maple Syrup

Maple syrup is the concentrated sap of sugar maple trees. It takes 40 gallons of tree sap, slowly simmered down, to make one gallon of maple syrup. Many people in the United States have never tasted true maple syrup. Because of the high cost of maple syrup, the food industry has developed substitutes. Most pancake syrups are only 2% maple syrup. The main ingredient in these syrups is corn syrup, another common sweetener in processed foods.

Corn Syrup

Corn syrup is processed by hydrolyzing cornstarch into glucose. Corn syrup is composed of varying amounts of dextrose, maltose, and dextrins or polysaccharides. (Dextrose is the name for glucose used by the confectionery trade.) A sweeter version of corn syrup, called high-fructose corn syrup, is used in many products. These products include soft drinks, pancake syrups, candies, and baked goods. It is produced by enzymatically converting some of the dextrose in corn syrup to fructose.

Technology has made it possible to use enzymes to convert starch from abundant corn supplies into sweet syrups. This has economic benefits because corn is a plentiful crop in the United States. Being able to use corn sweeteners makes it possible for food manufacturers to keep processed food prices stable.

Besides its availability and cost benefits, corn syrup has the advantage of being flexible in its properties. It is sometimes used to increase the viscosity, or thickness, of food products. Its sweetness can be varied by altering the hydrolysis process. This allows corn syrup to be used successfully for a wider variety of manufactured food products than sucrose.

Sorghum

Sorghum is a "grass" crop that resembles corn in the field. Sweet sorghum is grown in many areas for its sweet syrup, which resembles molasses. Sap is squeezed from the sorghum canes and then slowly boiled to evaporate away the excess water. In some rural areas, it is possible to watch farmers making sorghum syrup.

Honey

The first sweetener to be used in food preparation was honey. Bees extract an invert sugar syrup from the pollen of flowers and store it in their hives for future use. Honey is about 75% invert sugar and 15% to 20% water.

Bees are useful for the plant pollination
process as well as the production of honey. Honey producers construct hives that give the producers easy access to the honey stores. The honey producers place the hives near large fields of plants. These plants have sweet blossoms that will give a pleasant flavor to the honey. Orange blossom honey comes from hives near large commercial orange groves. Clover honey comes from growers whose hives are located near large fields of clover.

**Isomalt**

Isomalt is a mixture of one part mannitol, one part sorbitol, and two parts beet sugar. It is very popular among baking and pastry chefs because of its unique properties. It liquefies at 310°F. It does not form crystals, colors easily, and remains clear. Because it does not form crystals, it can be blown and spun into a wide variety of sugar creations.

**Functions of Sugars in Food Preparation**

Sugars from all sources have chemical structures that are similar but not identical. The similarities allow food manufacturers to use one sugar in place of another for some purposes. However, the unique aspects of each sugar structure determine which type of sugar is best suited for each function in foods.

Sugars have up to six functions they can perform in food products. They act as sweeteners, preservatives, and tenderizers. They also have a key role in the processes of crystallization, caramelization, and fermentation.

**Sweeteners**

Sugar’s ability to sweeten is its major function in most food products. The ability to sweeten is connected to sugar’s molecular structure. Sugars contain up to ten basic units of monosaccharides. Sensory evaluations have shown that most people rate the sweetness of sugars similarly. That is, most agree fructose is sweeter than sucrose and lactose is the least sweet of the three. Scientists have compared the structure of sugar molecules to the sweetness of the sugars. The scientists have found the sweeter the sugar is, the simpler the structure of the molecule is. The longer the sugar chain is, the less sweet the sugar will seem to be. See 8-8.

Recent research has revealed more information about sugar’s ability to sweeten. Researchers have identified a triangular form on sugar molecules that bonds to taste buds for a short time. The nervous system registers this bond as a sweet flavor. The more of these bonding sites a molecule has, the sweeter the substance will seem to be. The perceived sweetness of the substance will also increase as the length of the bonding period increases.

**Preservatives**

Sugar helps prevent food spoilage. Water will be drawn to sugar molecules before it is drawn to bacteria. Therefore, most single-celled contaminants will dehydrate and die in concentrated sugar solutions. This is why sugar is the only preservative needed in most candies, jams, jellies, and syrups.

Sugar plays another preservative role in baked goods. It helps products such as cakes stay moist. Invert sugar has been found to maintain freshness of baked goods considerably longer than sucrose.

**Tenderizers**

When sugar is added to a dough, it will tenderize the product. You can observe the effects of this function by taste testing an

<table>
<thead>
<tr>
<th>Sugar</th>
<th>Relative Sweetness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fructose</td>
<td>1.8</td>
</tr>
<tr>
<td>Sucrose</td>
<td>1.0</td>
</tr>
<tr>
<td>Glucose</td>
<td>0.8</td>
</tr>
<tr>
<td>Mannitol</td>
<td>0.7</td>
</tr>
<tr>
<td>Glycerol</td>
<td>0.6</td>
</tr>
<tr>
<td>Sorbitol</td>
<td>0.5</td>
</tr>
<tr>
<td>Galactose</td>
<td>0.3</td>
</tr>
<tr>
<td>Maltose</td>
<td>0.3</td>
</tr>
<tr>
<td>Lactose</td>
<td>0.2</td>
</tr>
</tbody>
</table>

8-8 The sweetness of sucrose, or table sugar, is the standard to which the sweetness levels of other sugars are compared.
Sugar helps tenderize cakes, pastries, and doughnuts. The Italian bread on the left has a paler color and chewier texture because it does not contain any sugar. Compare this with white bread that contains a small amount of sugar. Also test a sweet roll that has almost twice the sugar of white bread. Most of the difference in tenderness of the three products is due to the sugar in the dough. You can observe the same characteristic by comparing a bread-type muffin and a basic white or yellow cake. See 8-9.

The tenderizing effect of sugar also changes the viscosity or pourability of a batter. Sugar interferes with the flour's ability to form an elastic structure. This allows the batter to flow or pour more easily than the same mixture without sugar.

Crystallizing Agents

In candies, sugars function as crystallizing agents. This function is linked to the solubility of sugars in water. Solubility is the ability of a solute to dissolve in a solvent. Sugar will dissolve in water because of its large number of hydroxyl groups. The position of the -OH causes the sugar molecule to have a polar nature near each hydroxyl group. These groups are then attracted to the polar water molecules, and hydrogen bonds are formed. These hydrogen bonds cause water molecules to surround the sugar molecules, suspending the sugar in a water solution. See 8-10.

Sugar's ability to dissolve in water increases as the temperature of the solution increases. The temperature of sugar solutions will steadily climb as heat is added. As the solution heats, water will evaporate. This changes the solute to solvent ratio, increasing the sugar concentration.

If a sugar solution has been heated to concentrate it and is then cooled, a supersaturated solution is created. Any solution that has been heated to dissolve more solute than the water would normally hold is called supersaturated.

Candy is made when sugar crystals separate from a supersaturated sugar solution during cooling. The entire candy industry revolves around understanding the concentrations of sugar to water at given temperatures. Candy producers know the optimum temperature for making each type of candy. See 8-11.

Sugar crystals form around particles that enter a sugar solution. These particles can be as tiny as lint or dust. However, the crystals that result may be large. Sugar crystals that form on the sides of the pan during cooking will also trigger further crystallization. This is why some candy recipes have you put a lid on the pan for two to five minutes. The steam trapped by the lid will wash sugar crystals from the sides of the pan.

Controlling the size of the sugar crystals is very important to the production of quality candy. In most cases, the finer the sugar crystals are, the higher the quality of the candy will be.
### Boiling Point of Sugar Solutions

<table>
<thead>
<tr>
<th>Boiling Point °C (°F)</th>
<th>Percentage of Sugar</th>
<th>Percentage of Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>100.4 (213)</td>
<td>10</td>
<td>90</td>
</tr>
<tr>
<td>101.0 (214)</td>
<td>30</td>
<td>70</td>
</tr>
<tr>
<td>102.0 (216)</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>106.5 (224)</td>
<td>70</td>
<td>30</td>
</tr>
<tr>
<td>107.3 (225)</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>114.9 (239)</td>
<td>85</td>
<td>15</td>
</tr>
<tr>
<td>117.7 (244)</td>
<td>87</td>
<td>13</td>
</tr>
<tr>
<td>120.8 (249)</td>
<td>89</td>
<td>11</td>
</tr>
<tr>
<td>122.6 (253)</td>
<td>90</td>
<td>10</td>
</tr>
</tbody>
</table>


8-11 As the concentration of the solute increases, so does the boiling point of the solution.

### Factors That Affect Crystal Formation

The following five factors affect sugar crystal formation:

- type of sugar
- use of interfering agents
- agitation of the sugar syrup
- cooling of the sugar syrup
- ripening of the finished product

### Type of Sugar

The main sugar used by candy producers is sucrose. Sucrose crystallizes rapidly and can form large crystals. Candy producers add invert sugar when they need to slow the crystal formation. You read earlier that invert sugar occurs naturally in honey and molasses. Invert sugar is also produced commercially. This is done through the controlled addition of acids to sucrose, followed by a neutralization process.

Invert sugar helps prevent the crystallization and resulting graininess of candy caused by cane and beet sugar. This is because invert sugar is a mixture of two monosaccharides and cane and beet sugars are disaccharides. Monosaccharides are more soluble in water and therefore form smaller crystals. It takes skill to make homemade candy that has the fine texture that results from the use of commercial invert sugar.

### Interfering Agents

Interfering agents are substances that can prevent or slow crystal growth. See 8-12. The most commonly used interfering agents are corn syrup, butter, and cream. Some recipes call for egg white, cream of tartar, or vinegar as interfering agents, too. Corn syrup is high

![Image of ingredients](image.png)
in the monosaccharide glucose. Glucose and fructose will consistently produce finer, smaller sugar crystals than sucrose. The fat molecules of butter and cream and the protein molecules of egg white help suspend and separate sugar crystals. This results in a smooth, creamy candy. Cream of tartar and vinegar are acids. Adding acids will hydrolyze the sucrose in a sugar solution. Hydrolysis results in increased levels of glucose and fructose.

**Agitation**

Agitation refers to the beating and stirring of a candy solution. The effects of agitation are directly related to the temperature of the candy solution. When the syrup is hot, even slight or occasional stirring increases the likelihood of crystal formation. Constant stirring of a cooled syrup prevents large crystals from forming and results in a smooth candy. This is why most fudge recipes specify letting the candy sit until it has cooled to 43°C (110°F). You are then to beat the candy vigorously until it begins to set. This helps prevent sugar crystals from forming into large clusters, which would feel grainy.

**Cooling**

Cooling times for candy are critical to crystal formation and should not be cut short. Stirring too early can cause a few crystals to come out of the slightly supersaturated mixture. This causes crystallization to occur slowly rather than rapidly. Crystals that form slowly are larger and give candy a grainy texture. Rapid crystallization creates small crystals, which give candy a high-quality, smooth texture. It can be difficult to wait patiently for candy to cool. However, this step is vital if the final texture is to be smooth.

Fondants and taffies are often cooled on a marble slab. The candy syrup is poured on the cool stone. Thinning out the candy syrup on marble results in fast, even cooling that produces lots of small crystals.

**Ripening**

Ripening is allowing candy to sit for a period in order to form a creamy, smooth texture. Fondant is a type of candy that should be allowed to ripen. It is wrapped securely and then allowed to sit for 12 to 24 hours. This wait allows the time needed for smaller crystals to dissolve. The result is a smoother, moister fondant that kneads more easily. Some fondants have invertase added after cooking to cause further hydrolysis of disaccharides into invert sugar. The invert sugar results in a candy with a smooth, fine, even texture that is semisoft to liquid.

**Tips for Successful Candy Making**

Two factors must be carefully monitored when making candy. The first factor is the concentration of the sugar solution. The second factor is the size of the sugar crystals. Both of these factors are related to the temperature of the sugar solution. Therefore, it is important that your candy thermometer be calibrated every time you make candy. (You can review the calibration process by looking back at Chapter 5.)

The concentration of the sugar solution is directly related to temperature. If the solution is a few degrees too low, the sugar concentration will not be high enough. If you are making fudge, you will end up with a sticky sauce instead of a creamy candy. If the solution is a few degrees too high, the sugar concentration will be too high. This will turn your creamy fudge into a crumbly, grainy, dry product. When making caramels or suckers, a few degrees mean the difference between a delicious candy and an inedible, burnt one. See 8-13.

Keeping an eye on the candy thermometer is the easiest way to monitor the relative sugar-to-water concentration. However, remember that sugar tends to draw water. Therefore, a very humid day will change the sugar-water balance in candy as it cools. This is why some cookbooks will tell you never to make fudge on a rainy day. The high humidity may reduce the sugar concentration just enough to keep your fudge from setting. Candy manufacturers can prevent this problem by carefully monitoring and controlling the environment in the processing plant.

**Caramelizing Agents**

A fifth function of sugars in food products is to act as caramelizing agents. When sugar is subjected to high or prolonged heat, it
Candy Stages and Sugar Solution Temperatures

<table>
<thead>
<tr>
<th>Stages</th>
<th>Temperature Ranges °C (°F)</th>
<th>Candies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thread</td>
<td>110–113 (230–235)</td>
<td>Candy creams or centers</td>
</tr>
<tr>
<td>Soft ball</td>
<td>113–118 (236–244)</td>
<td>Fondant, fudge, marshmallows</td>
</tr>
<tr>
<td>Ball</td>
<td>121–124 (250–255)</td>
<td>Caramel</td>
</tr>
<tr>
<td>Hard ball</td>
<td>127–130 (261–266)</td>
<td>Taffy, divinity</td>
</tr>
<tr>
<td>Soft crack</td>
<td>132–135 (270–275)</td>
<td>Butterscotch, popcorn balls</td>
</tr>
<tr>
<td>Crack</td>
<td>135–138 (275–280)</td>
<td>Nougat, toffee</td>
</tr>
<tr>
<td>Hard crack</td>
<td>140–157 (284–315)</td>
<td>Suckers, hard candy, peanut brittle, candied apples</td>
</tr>
<tr>
<td>Caramelized sugar</td>
<td>163–177 (325–351)</td>
<td>Coating for flan</td>
</tr>
</tbody>
</table>

* Stages refer to the physical characteristics of a small amount of syrup cooled quickly in a cup of ice water. This method of testing candy can be used if a thermometer is not available.

8-13 The sugar solution for each type of candy must be cooked to the correct temperature. Just 2°F made the difference between the soft fudge on the left and the creamy fudge in the middle. Another 2°F turned the creamy fudge into the dry, crumbly product on the right.

changes into a brown liquid. This is called **caramelization**. It is a complex chemical process that has not been completely identified. Researchers know that dehydration, or loss of water, is at least partially responsible for the browning and resulting flavor changes. Hydroxyl groups from some molecules and hydrogen atoms from others combine to form water that evaporates in the high heat. The sugar molecules recombine, having a higher carbon concentration. Commercially, sucrose is heated in solution with acids or acidic ammonium salts to produce caramel flavoring and coloring.

Caramelization is at least partially responsible for the brown crust on baked goods and toast. Caramelization also causes the beige color of evaporated milk and the distinctive color and flavor of caramel candy. Flan, a caramel custard, is a classic example of caramelization in cooking. Flan is made by browning sugar in a heavy pan until it liquefies and turns a golden brown color. This rich syrup is quickly poured into a custard cup or
mold and swirled around to coat the bottom and sides. Custard is then poured into the cup or mold and baked. When the dessert is turned out of the cup or mold, the caramelized sugar syrup forms a flavorful coating for the custard.

Fermenting Agents

Sugar plays a major role in the fermentation process involved in the production of wines, beers, and yeast breads. Desired changes in these food products are caused by helpful microorganisms, such as yeast. Sugar fuels the fermentation process by serving as a food supply for the microorganisms. Alcohol is a by-product of this process, as illustrated by the following equation:

\[
glucose + \text{yeast} \rightarrow \text{ethanol}
\]

(You will read more about fermentation in Chapter 17.)

The Nutritional Value of Sugar

All sugars produce 4 calories per gram when digested. The body uses this energy to move muscles and maintain body functions. Learning how the body accesses the energy in sugar will help you understand the role of sugar in the diet. You will also be able to recognize sugar's relation to several major health concerns.

Once simple sugars are absorbed into the bloodstream, they head to the liver. Fructose and galactose are changed into glucose in the liver. This extra step slows their availability to the body's cells and helps provide the steady supply of glucose the body needs. Glucose that is not needed immediately is changed into glycogen. Glycogen is multibranched chains of glucose.

The body stores two-thirds of its glycogen in the muscles and the remaining third in the liver. When the body needs energy, single glucose molecules can be broken off each branch of a glycogen molecule simultaneously. This enables large amounts of glucose to be available very quickly. During intense exercise, the body can use up to one-fifth of its total glycogen stores in 20 minutes. The body is constantly using and replenishing its glycogen stores. See 8-14.

Studies have found the body needs sugars for proper digestion of fats and proteins. If there are no sugars present, toxins can build up in the blood that will eventually result in kidney damage.

A steady supply of glucose is needed for the brain to function. Sugars also increase the release of a brain chemical called serotonin. This chemical has a calming effect and acts as an antidepressant. After eating large amounts of sugar, people will become sleepy.

Although some monosaccharides are sweeter than others, it does not matter what form of sugar is eaten. Sugar is sugar as far as the body is concerned. The average U.S. diet provides about 18% of calories from sugars that are added to foods. Registered dietitians recommend that people reduce the percentage of calories consumed from added sugars to no more than 10%.

Health Concerns Related to Sugar Intake

Many people believe sugar causes tooth decay, aggravates diabetes, and causes weight gain. Although there is some truth to all these claims, there are also many misconceptions. According to an FDA report, sugar cannot be linked to any disease when consumed in moderate quantities.

Dental Caries

Dental caries, or tooth decay, is caused by acid damaging the enamel coating on teeth. Bacteria that live in the mouth feed on sugars and produce a sticky film called plaque. The
sticky nature of plaque causes it to adhere to the teeth, creating an oxygen-deprived environment. When oxygen is reduced, the bacteria release lactic, pyruvic, and acetic acids. These acids will slowly dissolve tooth enamel.

Sugar can cause dental caries, but so can any food that contains carbohydrates. Bread or crackers are as likely to cause tooth decay as sugar. It is not so much the food you eat but how long it stays on your teeth that causes decay.

Many communities add fluoride to water supplies. Drinking fluoridated water helps increase the resistance of tooth enamel to decay. However, keeping your teeth clean is the best way to prevent tooth decay. Regular brushing with a fluoride toothpaste will help slow the production of plaque. Daily flossing will help remove plaque that is clinging to teeth. Seeing a dentist regularly is also an important part of caring for your teeth.

### Item of Interest

#### Controlling Tooth Decay

- Brush your teeth after eating concentrated sources of sugars that can help dental caries develop. High-sugar foods include candies, syrups, soft drinks, and some breakfast cereals.
- Limit sticky foods. They are more of a problem than sweet ones. The stickiest carbohydrates are found in foods like crackers, cereals, and pretzels. Saliva washes sugars away fairly quickly. Complex carbohydrates can cling to the teeth where they are broken down into sugar.
- Limit how often you eat sugary foods. The amount of sugar you eat is not as great a factor as the frequency with which you eat it. Constant sucking on candy leads to increased tooth decay.
- Limit your consumption of acidic beverages. Acids eat away enamel, increasing tooth decay. All soft drinks are acidic. Sipping diet sodas all day continually bathes the teeth in acid. Try sipping water instead.
- Chew a piece of sugarless gum for at least 10 minutes after eating if you cannot brush your teeth. Gum stimulates the flow of saliva, which aids in clearing food particles from the teeth and neutralizes the acid. Sugared gum can be a problem if you chew one piece after another.
- Eat a small amount of aged cheeses in conjunction with or just after sugary foods. The cheese reduces acid levels in the mouth. Examples of aged cheeses include Cheddar, Monterey Jack, and Swiss.
- The American Dental Association recommends fluoride treatments as soon as teeth appear.
- Use fluoridated toothpaste. Dentists recommend fluoride supplements for children up to age 16 in areas where water is not fluoridated. Foods high in fluoride are tea and fish with edible bones.

Diabetes Mellitus

Diabetes mellitus is the body’s inability to move glucose from the bloodstream to the cells. Insulin is a hormone produced by the pancreas. It allows glucose to move into the cells for use as energy. People who have diabetes either do not produce enough insulin, or their bodies fail to recognize its presence. Therefore, diabetics are unable to handle sudden large surges of sugar in their bloodstream.

In the past, doctors recommended that diabetics eliminate sugar from their diets. Many believed excess sugar would cause diabetes. Research indicates the best diet for a diabetic is not much different from an ordinary healthful diet. In 1994, the American Diabetes Association concluded that there is no one right diet for diabetics. Guidelines need to be based on individual weight, cholesterol levels, and other health factors.

Diabetics must avoid sugar “spikes” in their diets. Health experts recommend a diet that will keep blood glucose levels fairly steady throughout the day. Diabetics can best changes in your diet if you are diabetic.

Keep sucrose intake to less than 10% of total calories. Sugar can be eaten in small amounts. There is no difference in the way a diabetic handles any carbohydrates. Diabetics can eat sugar provided it replaces other high-carbohydrate foods and is part of a meal.

Limit foods containing high-fructose corn syrup. Fructose is okay when found in fruits and vegetables. The problem is the high level in high-fructose corn syrup, which is often used in drinks and cookies. Large amounts can raise blood sugar, cholesterol, and triglyceride levels. Switch to monounsaturated fats. Three recent studies indicate that these fats are better for helping control blood sugar levels. Do not increase total fat intake! Good sources of monounsaturated fats (defined in Chapter 10) are olive oil, canola oil, some nuts, and avocados.

Watch your weight. Excess body fat interferes with the work of insulin. The more overweight a diabetic is, the more problems he or she is likely to have controlling blood sugar levels. Exercise and watch total calorie intake!

Increase vitamin C and E. High blood sugar levels increase cell-damaging free radicals. Recent studies indicate that neutralizing free radicals may reduce the risk of diabetic complications. Talk to your doctor about these findings.

achieve this by eating nutritious foods in five to six small meals a day. This advice is probably the best preventive medicine for anyone with a family history of diabetes.

Weight Gain

Many people blame excess sugar in their diets for weight gain. However, the key to weight control is balancing calories going into the body with calories being burned by the body. All excess calories, whether from sugar, starch, fat, or protein, will be stored in the body as fat. Therefore, too much of any type of food can lead to weight gain.

It is possible to maintain a healthy weight and still enjoy foods that provide sugar. The important point to remember is to practice moderation. Many foods that are high in added sugar provide few other nutrients. Such foods should be consumed sparingly so they do not replace other sources of nutrients in the diet. For instance, you might enjoy a can of regular soft drink. If you are eating a nutritious diet, you can probably afford the 150 calories from sugar the soft drink provides. However, four cans of regular soft drink would provide about 600 calories from sugar and no other nutrients but water. This is 30% of the average woman’s total daily calorie needs. Few people can get all the other nutrients their bodies need in the remaining 1,400 calories.

Recent research seems to indicate that the amount you eat is related more to the volume and mass of the food than its calorie content. The chart in 8-15 compares the volume, calorie content, and exercise needed to burn the extra calories in several foods. This chart shows how food intake, energy use, and body weight are related. A healthy weight requires knowledge about nutrition and exercise, moderation and balance in food choices, and learning to enjoy regular physical exercises.

<table>
<thead>
<tr>
<th>Foods to Satisfy Your Sweet Tooth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food (one cup portion)</td>
</tr>
<tr>
<td>Watermelon</td>
</tr>
<tr>
<td>Apple</td>
</tr>
<tr>
<td>Mandarin oranges</td>
</tr>
<tr>
<td>Chocolate pudding</td>
</tr>
<tr>
<td>Chocolate chips</td>
</tr>
</tbody>
</table>

*Exercise needed is based on a 130-pound person hiking at a moderate rate.

8-15 Equivalent volumes of food can vary greatly in their weight and calorie content.