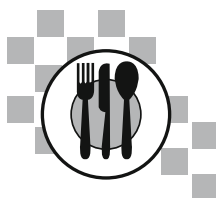

Part II

Carbohydrates in Food



Introduction

Carbohydrates are organic compounds containing carbon, hydrogen, and oxygen, and they may be simple or complex molecules. Historically, the term “carbohydrate” has been used to classify all compounds with the general formula $C_n(H_2O)_n$ as the hydrates of carbon. Important food carbohydrates include simple sugars, dextrans, starches, celluloses, hemicelluloses, pectins, and gums. They are an important source of energy or fiber in the diet, and they are also important constituents of foods because of their functional properties. Carbohydrates may be used as sweeteners, thickeners, stabilizers, gelling agents, and fat replacers.

The simplest carbohydrates are known as *monosaccharides* or sugars, and they have the general formula $C_nH_{2n}O_n$. The most common ones contain six carbon atoms. *Disaccharides* contain two sugar units, *trisaccharides* contain three, *oligosaccharides* contain several units, and *polysaccharides* are complex polymers containing as many as several thousand units linked together to form a molecule. These carbohydrates are discussed in this chapter.

Monosaccharides

Monosaccharides are simple carbohydrates containing between three and eight carbon atoms,

yet only those with five or six carbon atoms are common. Two of the most important ones in foods are the six-carbon sugars glucose and fructose. These have the general formula $C_6H_{12}O_6$.

Examples of Monosaccharides

Glucose. Glucose is known as an *aldose sugar* because it contains an aldehyde group (CHO) located on the first carbon atom of the chain:

Glucose and an aldehyde group:

It is conventional to number the carbon atoms along the chain so that the carbon atom with the highest number is farthest away from the aldehyde (or functional) group. The aldehyde group is therefore located on carbon one in glucose (and in all other aldose sugars). The numbering of the carbon atoms in glucose is shown in Fig. 3.1.

Two isomers of glucose exist, which are mirror images of each other, D-glucose and L-glucose. D-Glucose is the isomer that occurs naturally.

In fact, there are two series of aldose sugars, known as the D-series and the L-series, each formed by adding CHO groups to build the carbon chain, starting from the smallest aldose sugar, which is D- or L-glyceraldehyde (see Fig. 3.2).

Each H—C—OH group within the chain is asymmetrical (since the H and OH groups are different). The highest-numbered asymmetric carbon atom of each D-series sugar has the same configuration as D-glyceraldehyde, rather than its L-isomer. In glucose, the highest-numbered

For use with subsequent Carbohydrate food chapters

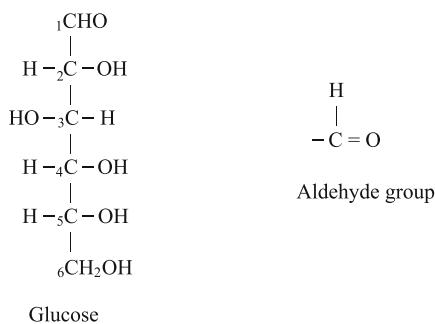


Fig. 3.1 Glucose and an aldehyde group

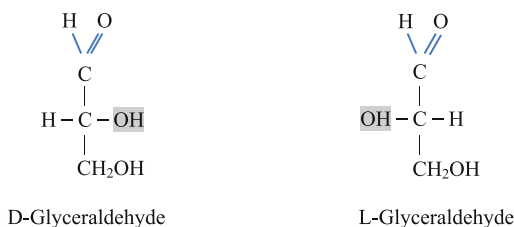


Fig. 3.2 Mirror images of glyceraldehyde

asymmetric carbon atom is carbon-5. This is termed the **reference carbon atom**, because its configuration determines whether the sugar belongs to the D-series or to the L-series. The hydroxyl group attached to it is called the **reference hydroxyl group**. This group is always on the right side in a D-series sugar.

The straight-chain configuration of glucose (and of other monosaccharides) does not account for all the properties of the molecule. In reality, the straight-chain form exists in equilibrium with several possible ring configurations. In other words, the different configurations exist together in solution in a delicate balance. Glucose can exist in four ring structures: two pyranose or six-membered ring forms, and two furanose or five-membered ring forms. These exist along with the straight-chain form, as shown in Fig. 3.3.

The most common configurations for glucose are the **pyranose** structures, drawn according to the Haworth convention in Fig. 3.4. These are **anomers** and are designated **alpha** (α) and **beta** (β). They are formed when the hydroxyl group on the fifth carbon reacts with the carbonyl group

(located on the first carbon, designated as C1). As the ring closes, a new hydroxyl group is formed on C1. This is termed the **anomeric hydroxyl group**, and the carbon atom to which it is attached is termed the **anomeric carbon atom**. For glucose and the other aldoses, the anomeric carbon atom is always the first carbon atom of the chain.

The anomeric hydroxyl group can project towards either side of the ring, as shown in Fig. 3.4. Hence, there are two possible pyranose structures.

For glucose and all the hexoses, the α -anomer has the anomeric hydroxyl group on the *opposite* face of the ring to carbon-6 (i.e., pointing in the opposite direction to carbon-6), when drawn according to the Haworth convention, whereas the β -anomer has the anomeric hydroxyl group on the *same* face of the ring as carbon-6 (i.e., pointing in the same direction as carbon-6). For the D-series sugars, when the ring closes, carbon-6 is always located above the plane of the ring. Therefore, in the case of the α -anomer, the anomeric hydroxyl group points *down*, or *below* the plane of the ring, whereas in the case of the β -anomer, the anomeric hydroxyl group points *up*, or *above* the plane of the ring.

Alpha-anomer—anomeric hydroxyl group is on the **opposite** face of the ring to carbon-6
D-series sugars—anomeric hydroxyl group points **down**
Beta-anomer—anomeric hydroxyl group is on the **same** face of the ring as carbon-6
D-series sugars—anomeric hydroxyl group points **up**

[For the chemists who prefer to define the alpha- and beta-configurations according to the reference carbon, when the anomeric hydroxyl group is formed on the same side of the ring as the reference hydroxyl group (as seen in the Fischer projection formula), the anomer is denoted alpha, whereas, when it is formed on the opposite side, it is denoted beta.]

Fig. 3.3 The main isomers of D-glucose (Fischer projections)

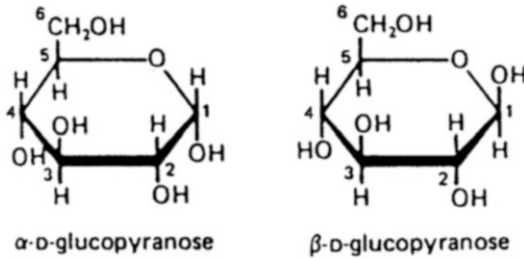
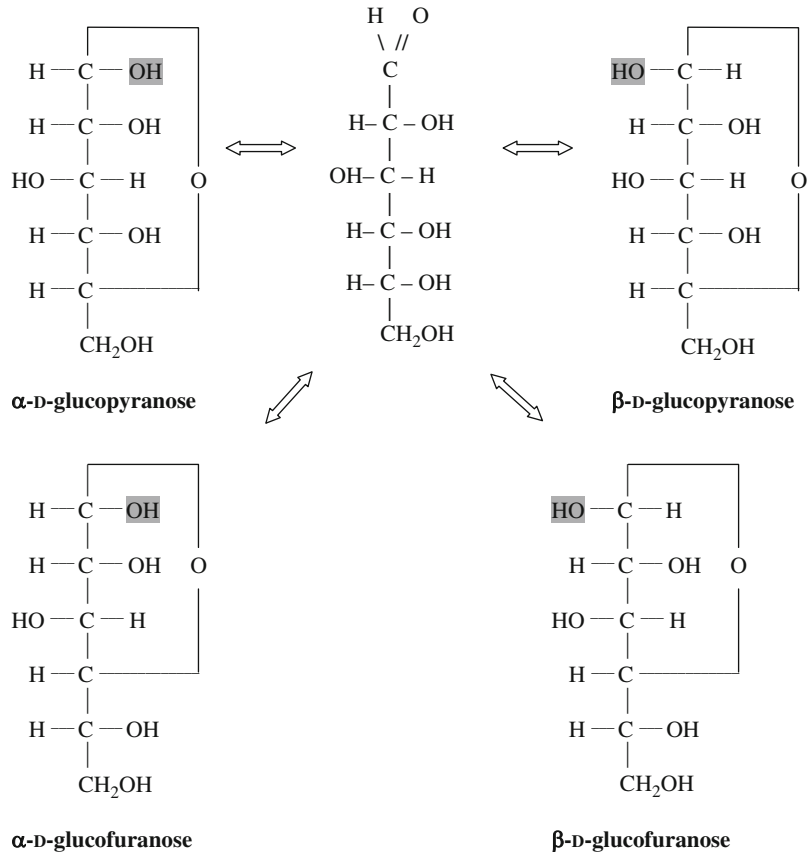


Fig. 3.4 The D-glucopyranose anomers, drawn according to the Haworth convention

In solution, the alpha- and beta-forms are in equilibrium, yet the configuration can be fixed if the molecule reacts to form a disaccharide. It is important to know whether the configuration is fixed as the alpha- or beta-configuration, because this affects properties of the molecule, including digestibility. For example, starch contains

α-D-glucose molecules, and so can be digested, although cellulose contains β-D-glucose molecules and is indigestible.

Although the ring structures are drawn with flat faces in the Haworth formulae, in reality they are not planar rings, yet, rather, they are bent, and could be visualized more as a boat or a chair configuration, as shown in Fig. 3.5.

The different configurations of glucose and the relationships between them are complex, and are beyond the scope of this book. For a more in-depth treatment, interested readers are referred to books such as Food Chemistry, edited by Owen Fennema, or to basic biochemistry textbooks.

Glucose is the most important aldose sugar. Two other aldose sugars important in foods include galactose and mannose. Galactose is important as a constituent of milk sugar (lactose),

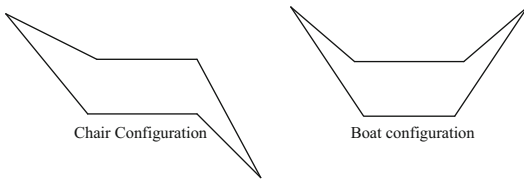


Fig. 3.5 Chair and boat configurations of monosaccharides

and mannose is used to make the sugar alcohol mannitol, which is used as an alternative sweetener in chewing gum and other food products. These are both D-series sugars. In fact, almost all naturally occurring monosaccharides belong to the D-series.

Fructose. Fructose is a six-carbon sugar, like glucose, although despite this, it is a **ketose sugar**, not an aldose, because it contains a ketone group, and not an aldehyde group (see Fig. 3.6):

Similarly to the aldose sugars, there is a D-series and an L-series of ketose sugars, but D-fructose is the only ketose of importance in foods. All **ketose sugars** contain a ketone group, not an aldehyde group.

In fructose, the ketone group is located on the second carbon of the chain. The second carbon atom is therefore the anomeric carbon in fructose. Fructose occurs mainly in the α - and β -*furanose*, or five-membered ring configurations, as shown in Fig. 3.7.

Both the ketone groups of a ketose sugar and the aldehyde group of an aldose sugar may be called a **carbonyl group**. A carbonyl group contains a carbon atom double-bonded to an oxygen atom, but the other atoms are not specified. Hence, an aldehyde group is a specific type of carbonyl group, with both a hydrogen atom and an oxygen atom attached to the carbon atom. A ketone group is also a carbonyl group, because it contains an oxygen atom double-bonded to a carbon atom located within a hydrocarbon chain.

Disaccharides

Disaccharides contain two monosaccharides joined together with a special linkage, called a **glycosidic**

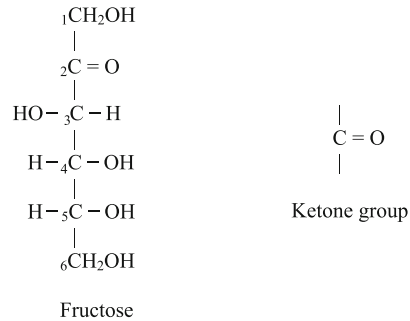


Fig. 3.6 Fructose and a ketone group

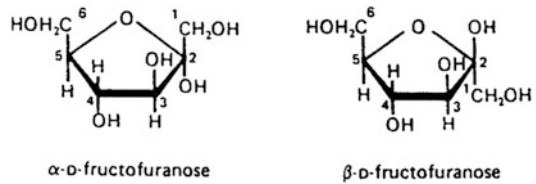


Fig. 3.7 The main configurations of D-fructose

bond. Several disaccharides are important in foods—sucrose or table sugar is the most common and contains glucose and fructose. There are other important disaccharides, such as maltose, containing two glucose units, and lactose, which contains glucose and galactose. Lactose is also known as milk sugar because it is found in milk. It is the least sweet and least soluble of the sugars.

Glycosidic Bonds

A **glycosidic bond** is formed when the carbonyl group of one monosaccharide reacts with a hydroxyl group of another molecule and water is eliminated (see Fig. 3.8).

Formation of a glycosidic link fixes the configuration of the monosaccharide containing the involved carbonyl group in either the α - or β -position. Therefore, it is necessary to specify whether the link is an α - or a β -link. The position of the bond must also be specified. For example, when two glucose molecules are joined to make maltose, the glycosidic link occurs between carbon-1 of the first glucose molecule and carbon-4 of the second, and the configuration of the first glucose molecule is fixed in the α -position. Maltose therefore contains

Fig. 3.8 A glycosidic bond between the carbonyl and hydroxyl groups of monosaccharides

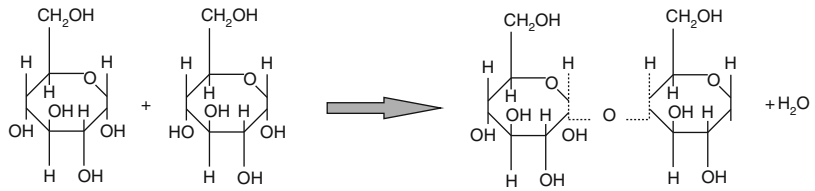
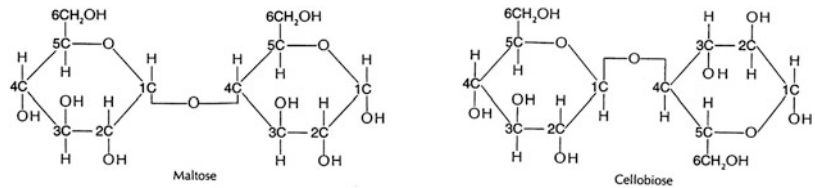


Fig. 3.9 Maltose and cellobiose



two glucose units linked by an α -1,4-glycosidic bond. The anomeric hydroxyl group that is not involved in the glycosidic bond (i.e., the one on the second glucose molecule) remains free to assume either the α - or β -configuration. Therefore, there are two forms of the disaccharide in equilibrium with each other.

Glycosidic bonds are stable under normal conditions yet can be hydrolyzed by acid and heat, or by enzymes such as sucrase, invertase, or amylases.

and carbon-4 of the second monosaccharide, as occurs in maltose

- Readily hydrolyzed by
 - Heat and acid
 - Certain enzymes, such as sucrase, invertase, and amylases

Glycosidic Bond

- Formed between the free carbonyl group of one monosaccharide and a hydroxyl group of another monosaccharide
- Fixes the configuration of the monosaccharide containing the involved carbonyl group in either the α - or β -position
- It is necessary to specify
 - The **configuration** of the link—whether it is an α -link or a β -link
 - The **position** of the link—it is numbered according to the respective positions of the two carbon atoms it links together. For example, an α -1,4 glycosidic link would occur between carbon-1 of the first monosaccharide

(continued)

Examples of Disaccharides

Maltose and Cellobiose. As has already been mentioned, maltose contains two glucose units linked by an α -1,4-glycosidic bond. When two glucose molecules are joined together and the configuration of the first glucose molecule is fixed in the β -position, cellobiose is formed. Cellobiose contains a β -1,4-glycosidic bond. The chemical formulas for maltose and cellobiose are shown in Fig. 3.9.

Maltose is the building block for *starch*, which contains α -1,4-glycosidic bonds. Alpha links can be broken down by the body, so starch is readily digested. Cellobiose is the building block for *cellulose*, which contains β -1,4-glycosidic bonds. Cellulose cannot be digested in the human body because the β -linkages cannot be broken down by the digestive enzymes. Therefore, cellulose is known as dietary fiber. (The glycosidic bonds in cellulose cross the plane of the monosaccharide

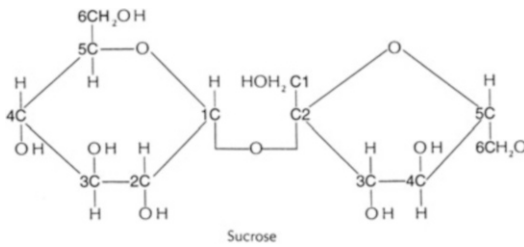


Fig. 3.10 Sucrose

units they join together, and so they may be termed **cross-planar bonds**. It is because they are cross-planar that they are not digestible. In reality, because of the orientation of the bonds, the monosaccharide units tend to twist or flip over, as drawn in Fig. 3.9, which results in a twisted ribbon effect for the polymer chain.)

Sucrose. Sucrose is the most common disaccharide, and it contains glucose and fructose joined together by an α -1,2-glycosidic link (see Fig. 3.10). The carbonyl groups of both the glucose and the fructose molecule are involved in the glycosidic bond; thus, the configuration of each monosaccharide becomes fixed. Glucose is fixed in the α -configuration, whereas fructose is fixed in the β -configuration. Sucrose can be hydrolyzed to glucose and fructose by heat and acid, or by the enzymes invertase or sucrase. The equimolar mixture of glucose and fructose produced in this way is called **invert sugar**. Production of invert sugar is important during the formation of candies and jellies, as invert sugar prevents unwanted or excessive crystallization of sucrose. (For further discussion of crystallization of sucrose, see Chap. 14.)

Various Properties of Sugars

Sweetness

The most obvious sensory property of sugars such as glucose, fructose, and sucrose is their **sweetness**, which varies depending on the specific sugar. Lactose (milk sugar) is the least sweet, whereas fructose is the sweetest sugar. Sugars are used as sweeteners in candies and many other food products.

Formation of Solutions and Syrups

Sugars are soluble in water and readily form syrups. If water is evaporated, crystals are formed. Sugars form **molecular solutions** due to hydrogen-bond interchange. When sugar is placed in water, the water molecules form hydrogen bonds with the sugar molecules, thus hydrating them and removing them from the sugar crystals. Solubility increases with temperature; thus, a hot sucrose solution may contain more solute than a cold one. (For a discussion of molecular solutions, see Chap. 2.)

If a hot saturated sucrose solution is cooled without disturbance, it will supercool, and a supersaturated solution will be obtained. A **supersaturated solution** contains more solute than could normally be dissolved at that temperature. It is unstable, and if stirred or disturbed, the extra solute will rapidly crystallize out of solution. Supersaturated solutions are necessary in candy-making. For more detail on sugar crystallization and candies, see Chap. 14.

Body and Mouthfeel

Sugars contribute body and “mouthfeel” to foods. In other words, the addition of sugar makes a food more viscous or gives it a less runny consistency. If sugar is replaced by a non-nutritive or high-intensity sweetener such as aspartame or saccharin, the consistency of the food will be watery and thin. To prevent this, another substance has to be added to give the expected body or mouthfeel to the food. Modified starches or gums are usually added to such food products to give the desired consistency without addition of sugar.

Fermentation

Sugars are readily digested and metabolized by the human body and supply energy (4 cal/g). They are also metabolized by microorganisms. This property is important in breadmaking, where sugar is fermented by yeast cells. The

yeast feeds on the sugar, producing carbon dioxide, which is the leavening agent and causes bread dough to rise before and during baking.

Preservatives

At high concentrations, sugars prevent growth of microorganisms, because they reduce the water activity of food to a level below which bacterial growth cannot be supported. Sugars can, therefore, be used as preservatives. Examples of foods preserved in this manner include jams and jellies.

Reducing Sugars

Sugars that contain a free carbonyl group are known as *reducing sugars*. All monosaccharides are reducing sugars. Disaccharides are reducing sugars only if they contain a free carbonyl group. Sucrose is not a reducing sugar because it does not contain a free carbonyl group. The carbonyl groups of glucose and fructose are both involved in the glycosidic bond and are, therefore, not free to take part in other reactions. Maltose, on the other hand, has one carbonyl group involved in the glycosidic bond, and the other carbonyl group is free; thus, maltose is a reducing sugar.

Reducing sugars give brown colors to baked goods when they combine with free amino acid groups of proteins in a browning reaction called the *Maillard reaction* (this reaction is discussed further in Chap. 8).

Caramelization

Sugars *caramelize* on heating, giving a brown color. Caramelization is caused by the decomposition of the sugars and occurs at extremely high temperatures. A variety of compounds are formed as a result, including organic acids, aldehydes, and ketones. The reaction does not involve proteins and should not be confused with the Maillard browning reaction.

Sugar Alcohols

Reduction of the carbonyl group to a hydroxyl group gives *sugar alcohols* such as xylitol, sorbitol, and mannitol. These compounds are sweet, although not as sweet as sucrose. However, they are not fermented as readily as sugar by microorganisms in the mouth, and so they are noncariogenic. (In other words, they do not cause tooth decay.) Therefore, they are used in chewing gum, breath mints, and other products that may be kept in the mouth for a while. Although products containing sugar alcohols may be labeled as “sugar-free,” it is important to realize that sugar alcohols are not free of calories. They are not metabolized as efficiently as sugars and have a lower caloric value (between 1 and 3 kcal/g).

Sugar alcohols may be used as a low-energy bulk ingredient (in place of sugar) in many food products. Since sorbitol is mostly transformed to fructose in the body rather than glucose, it is tolerated by diabetics. Hence, it can be used to replace sugar in diabetic foods.

Oligosaccharides

Oligosaccharides contain a few (3–10) monosaccharide residues linked together by glycosidic bonds. Common ones include raffinose and stachyose. Raffinose is a *trisaccharide* and contains galactose, glucose, and fructose. Stachyose contains glucose, fructose, and two galactose units. Both occur in legumes such as dry beans and peas. They are not hydrolyzed or digested by the human digestive system, and become food for bacteria in the large intestine. The bacteria metabolize the carbohydrates and produce gas, causing varying degrees of discomfort.

Polysaccharides

The most important food *polysaccharides* are the starches, pectins, and gums. All are complex carbohydrate polymers with different properties,

which depend on the sugar units that make up the molecule, the type of glycosidic linkages, and the degree of branching of the molecules. Starches are discussed in Chap. 4 and pectins and other polysaccharides are covered in Chap. 5.

Dextrins and Dextrans

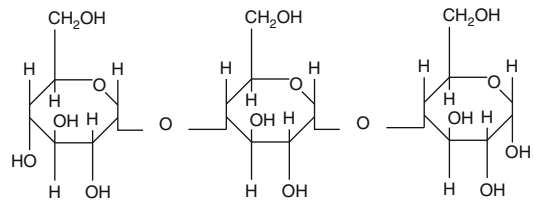
Dextrins are intermediate-chain length glucose polymers formed when starch is broken down or hydrolyzed. They are larger than oligosaccharides, considerably shorter than starch molecules. Dextrins contain glucose molecules joined by α -1,4-glycosidic bonds, and they are linear polymers. They are found in corn syrups, produced by hydrolysis of starch.

Dextrans are also intermediate-chain length glucose polymers, but they contain α -1,6-glycosidic bonds. They are produced by some bacteria and yeasts.

Starch

Starch is a glucose polymer that contains two types of molecules, known as amylose and amylopectin. These are shown in Figs. 3.11 and 3.12, respectively. Both are long chains of glucose molecules joined by α -1,4-glycosidic bonds; however, amylose is a linear chain, whereas amylopectin contains branches. For every 15–30 glucose residues there is a branch, joined to the main chain by an α -1,6-glycosidic link. The branches make amylopectin less soluble in water than amylose. Usually, the two types of starch occur together, although starches may contain only amylose or only amylopectin. They have different properties, which are discussed in Chap. 4.

Starches can also be modified to give specific functional properties in food products, so knowledge of the properties of different starches is important in the food industry. Chapter 4 gives detailed information on characteristics of different starches and their uses in foods.



α 1-4 glycosidic linkages of amylose

Fig. 3.11 Amylose

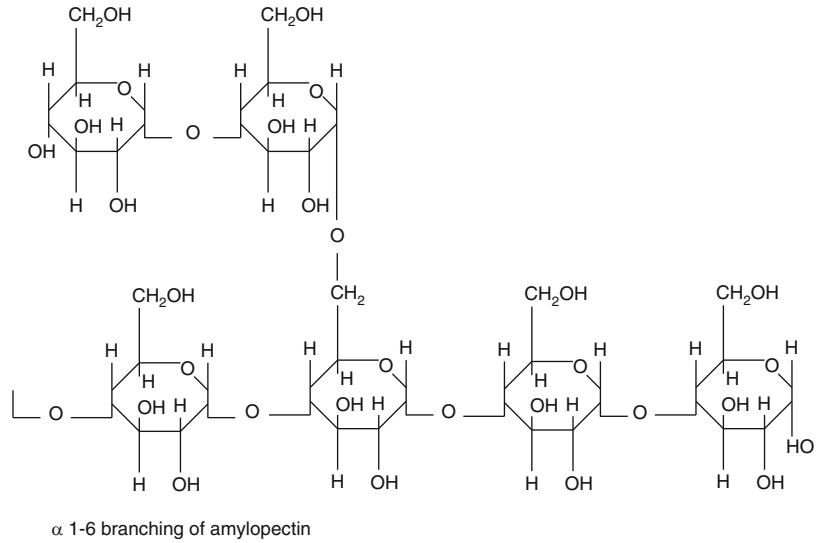
Pectins and Other Polysaccharides

Pectins, gums, and seaweed polysaccharides are also important carbohydrates used in food products. They are discussed further in Chap. 5. Pectins occur naturally in plant food products, yet gums and seaweed polysaccharides do not come from edible plant sources. They are extracted and purified and then added to food products.

Pectins are used mainly as gelling agents in jellies, jams, and other products. They are also used as stabilizers and thickeners. They are found in fruits and vegetables, and they help to hold the plant cells together. Structurally, they are long-chain polymers of α -D-galacturonic acid, which is an acid derived from the simple sugar galactose. They are soluble in water, and, under appropriate conditions, they form gels. Their structure and properties are discussed in Chap. 5.

Gums are mainly plant extracts and include gum tragacanth and guar gum. They are highly branched polysaccharides that form very viscous solutions, trapping large amounts of water within their branches. Most do not form gels because of the high level of branching. They are useful as thickeners and stabilizers, particularly in reduced-fat salad dressings and in other convenience foods.

Seaweed polysaccharides include the agars, alginates, and carrageenans. They are classified as gums, although they are able to form gels, unlike most gums. They are useful as gelling agents, thickeners, and stabilizers in foods.

Fig. 3.12 Amylopectin

Cellulose and *hemicellulose* are structural polysaccharides that provide support in plant tissues. They are not digested in the body, so they do not supply energy. However, they provide insoluble dietary fiber, which is an important part of a healthy, balanced diet.

Regarding *fiber*, food items may make the claim “good source of fiber” if 2.5–4.9 g of fiber per serving are present. When 5 g per serving, or more, are present, a food item may be labeled “high fiber.” It is recommended by health agencies and Dietary Guidelines for Americans that men should consume 38 g of fiber per day, and that women should consume 25 g per day. There is soluble and insoluble fiber and they are structurally different (see Chap. 4).

Inulin is a polysaccharide with the general formula $(C_6H_{10}O_5)_n$. It is found in tubers and

the roots of various plants and, when hydrolyzed, yields fructose.

Conclusion

Carbohydrates come in various shapes and sizes, from small sugar molecules to complex polymers containing thousands of simple sugar units. The digestible carbohydrates provide energy (4 cal/g), whereas the indigestible ones are an important source of dietary fiber. In addition to their nutritional value, carbohydrates are important as thickeners, stabilizers, and gelling agents. They are used in a wide spectrum of convenience foods, and, without them, the range of food products relished today would be greatly diminished.

Notes

CULINARY ALERT!

Glossary

Aldose Sugar containing an aldehyde group monosaccharide—single sugar unit.

Alpha-anomer The anomeric hydroxyl group is on the opposite face of the ring from carbon-6 (i.e., the two groups point in opposite directions).

Anomeric carbon atom The carbon atom that is part of the free carbonyl group in the straight-chain form of a sugar.

Anomers Isomers that differ only in the orientation of the hydroxyl group on the anomeric carbon atom; there are two forms—alpha (α) and beta (β).

Beta-anomer The anomeric hydroxyl group is on the same face of the ring as carbon-6 (i.e., the two groups point in the same direction).

Carbonyl group Contains an oxygen atom double-bonded to a carbon atom. The aldehyde group and the ketone group can both be described as a carbonyl group.

Caramelization Decomposition of sugars at very high temperatures resulting in brown color.

Cross-planar bond Formed when the hydroxyl groups on the carbon atoms involved in the formation of a glycosidic bond are oriented on opposite faces of the sugar rings. Cross-planar bonds occur in cellobiose and in cellulose. They also occur in pectin. They are not digested in the human digestive system.

Dextrans Glucose polymers joined by α -1,6-glycosidic bonds. Produced by some bacteria and yeasts.

Dextrins Glucose polymers joined by α -1,4-glycosidic bonds. Product of starch hydrolysis. Found in corn syrups.

Disaccharide Two sugar units joined together by a glycosidic bond.

Furanose Five-membered ring.

Glycosidic bond Bond that links two sugar units together; it is formed between the free carbonyl group of one sugar and a hydroxyl group of another sugar; the orientation (α or β) and position (e.g., 1,4) of the link must be specified.

Hydroxyl group The —OH group on the carbon atom.

Invert sugar An equimolar mixture of glucose and fructose, formed by hydrolysis of sucrose, either by acid and heat, or by enzymes such as invertase or sucrase.

Ketose Sugar containing a ketone group.

Maillard reaction (Maillard browning reaction) Nonenzymatic browning reaction involving a reducing sugar and a free amino acid group on a protein.

Monosaccharide Single sugar unit.

Oligosaccharide Several (3–10) sugar units joined together by a glycosidic bond.

Polysaccharide Many (hundreds or thousands of) sugar units joined together.

Pyranose Six-membered ring.

Reducing sugar Sugar that contains a free carbonyl group.

Reference carbon atom The highest-numbered asymmetric carbon atom; C5 in glucose and fructose.

Reference hydroxyl group The hydroxyl group attached to the reference carbon atom.

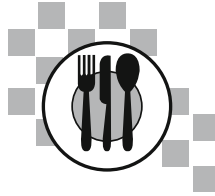
Sugar alcohol The result of reduction of carbonyl group to a hydroxyl group.

Supersaturated solution Solution that contains more solute than could normally be dissolved at a particular temperature.

Trisaccharide Three sugar units joined together by a glycosidic bond.

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Introduction

Starch is a plant polysaccharide stored in roots and seeds of plants, and in the endosperm of a grain kernel. It provides humans with energy (4 cal/g), and is hydrolyzed into glucose, supplying the glucose that is necessary for brain and central nervous system functioning.

Starch grains, or *granules*, contain long-chain glucose polymers and are *insoluble* in water. Unlike the small molecules of salt and sugar, the larger starch polymers do *not* form a true solution. Instead, starch granules form a *temporary suspension* when stirred in water. As *uncooked* granules, each may swell slightly when it absorbs water. However, once starch is *cooked*, the swelling is *irreversible* and the starch leaches out. This characteristic of starch granules enables starch to be used as a thickener.

Overall, the characteristics of a finished starch food product are determined by several factors: the source of starch, concentration of starch used in a formulation, the temperature and time of heating, and other components used with the starch, such as acid and sugar. There are many types of starch and modified starches. These thicken, prevent curdling, and stabilize cooked salad dressings, dips, gravies, desserts, and more.

Intermediate, shorter chain products from starch breakdown, known as dextrins, may be used to simulate fat in salad dressings and frozen

desserts. For example, wheat, potato, and tapioca maltodextrins may be used as fat replacers. These provide the viscosity and mouthfeel of fat in a food product, yet, with reduced calories compared to fat.

Starch Sources in the Diet

Starch sources are numerous, with common ones derived from cereal grains such as wheat, corn, or rice. Wheat yields a cloudy, thick mixture, while cornstarch produces more clear mixtures such as gravies or sauces. Vegetables, roots and tubers, including the root of cassava, and potatoes, are frequently used in the preparation of gluten-free foods, where persons with wheat allergies or intolerances do not use any wheat as a thickener. Specialty starches are available commercially and some may be available to the consumer, perhaps purchased through specialty food stores.

Another source of starch is legumes such as soybeans or garbanzo beans. As well, *sago* is a powdery starch obtained from the stems and trunks of the sago palm in tropical Asia. Sago may be used as a food thickener as well as a fabric stiffener. Fruits such as bananas may also be sources of starch.

Thus it may be seen that starch may come from a variety of sources. Depending on the source, starches may also have different crystalline structures.

Starch Structure and Composition

The starch *granules* from various grains differ in *size*, ranging in size from 2 to 150 μm . The *shape* of starches may also vary—being round or polygonal, as seen in the photomicrographs of corn, wheat, and waxy maize in Figs. 4.1, 4.2, and 4.3.

Starch is made up of two molecules, *amylose* and *amylopectin*, whose parts are connected by glycosidic linkages (see Chap. 3). **Amylose** molecules typically make up approximately one-quarter of starch. Amylose is a long linear chain composed of thousands of glucose units with attachment of the carbon 1 and carbon 4 of glucose units, and therefore contains α -1,4 glycosidic linkages. It forms a three-dimensional network when molecules associate upon cooling, and is responsible for the gelation of cooked, cooled starch pastes.

While those starches with a *high* amylose content are able to gel, or hold their shape when molded, starches *without* amylose thicken, although do *not* gel. Examples of the amylose content of various starch sources include:

Cereal grains—26–28 % amylose
Roots and tubers—17–23 % amylose
Waxy varieties of starch—0 % amylose

Amylopectin molecules (Chap. 3) constitute approximately three-quarters of the polymers in a starch granule. The glucose chain of amylopectin contains α -1,4 linkages, similar to amylose, however, with α -1,6 branching at every 15–30 glucose units of the chain. There is a linkage between the carbon 1 of the glucose and carbon 6 of the branch in amylopectin. The chains are highly branched and bushy (however less branched and less bushy than the *animal* storage form of carbohydrate, which is glycogen, *not* starch).

Starches with a high percentage of amylopectin will *thicken* a mixture, although cannot form a *gel* because, unlike amylose, amylopectin molecules do not associate and form chemical linkages. The greater the amylopectin content, the more viscous the starch paste (not a gel), while the greater the amount of amylose, the stronger the *gel*.

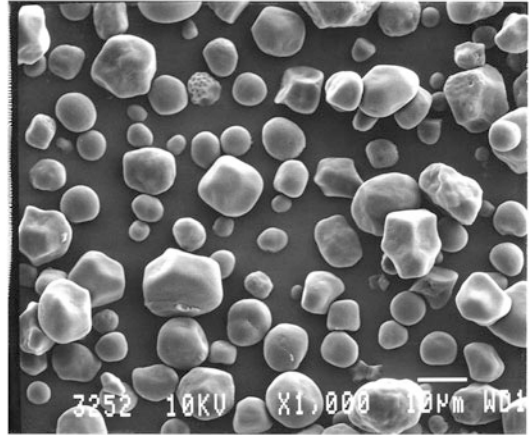


Fig. 4.1 Scanning electron micrograph of common corn cereal grains magnified 2,000 times (Source: Purdue University—Whistler Center for Carbohydrate Research)

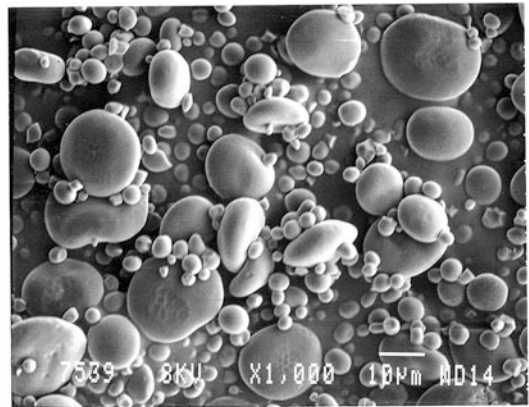


Fig. 4.2 Scanning electron micrograph of wheat magnified 600 times (Source: Purdue University—Whistler Center for Carbohydrate Research)

Gelatinization Process in Cooking

Steps in the process of becoming gelatinized will be enumerated in the following text. Starch in its *uncooked* stage is *insoluble* in water. Thus it cannot be referred to as “going into solution,” or “dissolving.” It forms a temporary *suspension* of large granules/particles, which are *undissolved* in the surrounding medium, and these particles will settle to the bottom of a container of liquid unless it is continuously stirred or otherwise agitated.

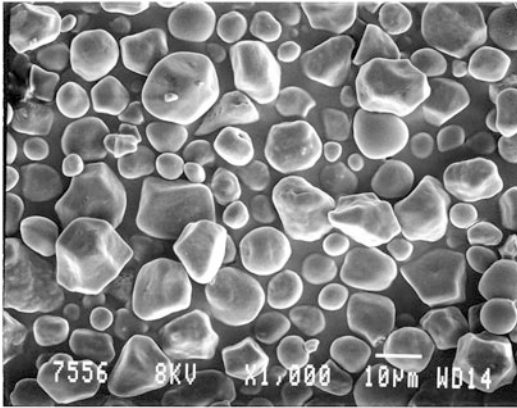


Fig. 4.3 Scanning electron micrograph of waxy maize magnified 1,000 times (Source: Purdue University—Whistler Center for Carbohydrate Research)

In a suspension, the starch particles may imbibe a small amount of water; however, generally, a suspension offers minimal change to the starch. Any uptake of water by the starch granule is reversible if starch is dried while still in the *uncooked* state.

Another feature of the *uncooked* starch molecule is that it exhibits a Maltese cross formation, or *birefringence* on the granule when it is viewed under polarized light with an electron microscope. This is due to the fact that it is a highly ordered crystalline structure, and light is refracted in two directions (Fig. 4.4).

Once cooking has begun when the starch is heated in surrounding water there occurs *imbibition*, or the taking of water into the granule. This first occurs in *less*-dense areas, and subsequently in the *more* crystalline regions of the starch molecule. At this *initial* point this is still a *reversible* step in the gelatinization process. However, as heating continues, starch granules take up more water *irreversibly* and swell; some short chains of amylose come out of the granules. This process, known as *gelatinization*, is responsible for the thickening of food systems. The gelatinized starch mixtures are opaque and fragile, and the ordered crystalline structure of starch is lost.

As starch leaches out of swollen granules in the gelatinization process, the water–starch mixture becomes a *sol*. A sol is a colloidal two-phase system containing a liquid continuous phase and

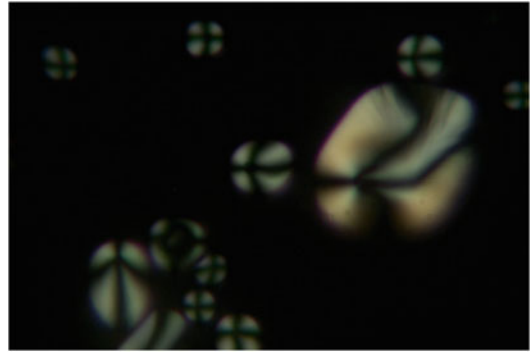


Fig. 4.4 Graph of the thickening of various starches (Source: Schoch TJ. Starches in foods. In: *Carbohydrates Their Roles*, Schultz HW, Cain RF, Wrolstad RW, eds. Westport, CT: AVI Publishing Company, 1969. With permission)

a solid dispersed phase. This *solid-in-a-liquid* is pourable and has a low *viscosity* or resistance to flow.



Gelatinization may be synonymous with *pasting*, although the two terms may also be reported as sequential occurrences (Freeland-Graves and Peckham 1996). Whether a separate process or the continuation of gelatinization, *pasting* occurs with the continued heating of already gelatinized starch grains. The process involves a *loss* of the ordered crystalline structure in starch, which is observed as the *disappearance* of the Maltese cross formation when starch is viewed under polarized light with an electron microscope.

The temperature at which a starch loses its ordered crystalline structure, and gelatinizes, may actually be a *range* of temperatures specific to a starch. The granules within a starch will swell and thicken mixtures at slightly different temperatures, with the larger granules swelling earlier than smaller granules.

The **steps** in the gelatinization process are as follows:

- The gelatinization temperature is *reached*—approximately 140–160 °F (60–71 °C), depending upon the starch type, and is *completed* at 190–194 °F (88–90 °C), or higher.
- The kinetic energy of the hot water molecules breaks the hydrogen bonds between the starch

molecules. Hydrogen bond interchange occurs as starch forms hydrogen bonds with water molecules instead of other starch molecules. As hydrogen bonds are formed, water is able to penetrate further into the starch granule and swelling takes place. Sufficient water must be present to enter and enlarge the starch granule.

- Diffusion of some amylose chains occurs as they leach out of the starch granules.
- Birefringence and the ordered crystalline structure of the uncooked granule is lost. Increased translucency is apparent because the refractive index of the expanded granule is close to that of water.
- Granule swelling increases as the temperature increases. The larger starch granules are the first to swell.
- Swollen granules take up more space and the mixture thickens as the enlarged granules leach amylose and possibly amylopectin.
- The starch paste continues to become thicker, more viscous, and resistant to flow as it gelatinizes.
- The final step in the gelatinization involves the necessity of cooking the gelatinized starch mix—gravy, pie filling, and so forth—for 5 min or longer to develop flavor. Unnecessary overstirring thins the cooked starch mixture because the swollen starch granules implode, rupture, and lose some of the liquid held inside the enlarged granule.

Factors Requiring Control in Gelatinization

It is important to note that starches must first be *thoroughly* gelatinized in order to produce viscous pastes or strong gels. Several factors must be controlled during gelatinization in order to produce a high quality gelatinized starch mixture. (Starches that are not *thoroughly* gelatinized *cannot* produce viscous pastes or strong gels.)

These factors include the following:

Agitation: Agitation, or stirring both initially and throughout the gelatinization process, enables granules of starch to swell independently of one

another and creates a more uniform mixture, without lumps. Even so, as previously mentioned, excessive agitation after gelatinization is complete may rupture granules, and consequently thin starch mixtures.

Acid: Acid hydrolysis during cooking of starch granules results in fragmentation and the formation of *dextrins* or short chain polymers. Hydrolysis of the starch molecule results in less water absorption by the starch granule, thus a thinner *hot* paste and less firm *cooled* product. Therefore, the late addition of acid to a starch mixture is best, after starch has been gelatinized and begun to thicken. Acid is frequently added to starch sauces in the form of vinegar, tomatoes, fruit, or citrus juice

Enzymes: Starch may be hydrolyzed by the starch-splitting enzymes α -amylase, β -amylase, and beta-glucoamylase.

Endoenzymes such as α -amylase act anywhere on the starch chain and undamaged starch grains to degrade starch. The hydrolysis products of β -amylase are glucose, maltose, and dextrins, depending on the extent of hydrolysis that takes place, and this may be desirable in commercial breadmaking.

The *exoenzyme* β -amylase acts on α -1,4 glycosidic linkages from the nonreducing end, and on damaged amylose or amylopectin chains. This further hydrolyzes starch two glucose units at a time, thus producing maltose.

The β -amylase cannot hydrolyze starch beyond the branch points of amylopectin. The enzyme β -glucoamylase hydrolyses the α -1,4 link, producing glucose, and slowly hydrolyzes α -1,6 linkages in starch.

Fat and proteins: The presence of fat and protein (such as in meat drippings used to produce a meat gravy) initially coats or *adsorbs* to the surface of the starch granules causing a delay in hydration and viscosity. Fat “waterproofs” the starch granules so that water does not easily penetrate during the gelatinization process. Thus, with the presence of fat there is less granular swelling and less amylose exiting from the granule, resulting in a decreased viscosity of the starch paste and decreased gel strength.

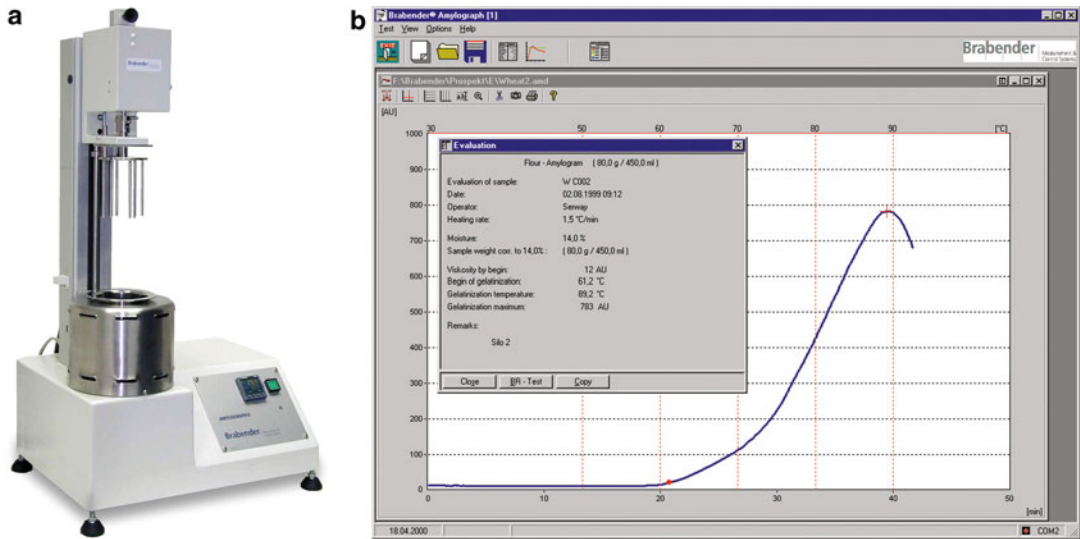


Fig. 4.5 Brabender amylograph and Brabender amylogram (Source: C.W. Brabender Instruments, Inc.)

Sugar: The addition of just moderate amounts of sugar, especially the disaccharides sucrose and lactose from milk, decreases starch paste viscosity, the firmness of the cooked and cooled starch product. Sugar competes with the starch for water and thus delays the absorption of water by starch granules. This prevents a speedy or complete swelling of the starch granule. Sugar also elevates the temperature required for gelatinization to occur.

As with acid addition, timing of sugar addition is significant. For a thicker mixture and gel, it is advised that a *partial* addition of sugar before the starch thickens and the remainder added later is best. Thus there is less sugar to compete with granule water absorption than if all of the sugar is added at the beginning of cooking.

If *both* acid and sugar are added to a starch mixture, there is less swelling due to the presence of sugar that competes with starch for water and there is less hydrolysis from acid, on the granule.

Salt: raises the temperature at which a starch mixture thickens.

Temperature: as previously mentioned, there is a range of temperatures, 190–194 °F (88–90 °C), that need to be met for gelatinization to occur.

The *completion* is up to 203 °F (95 °C), although starches vary in their gelatinization temperature.

Length of heating: Enough time is required for all the granules to swell (especially the large ones) but as the heating is lengthened, the finished mixture may be thinner due to possible overstirring and rupturing of enlarged granules. Alternatively, cooking for a long time in an uncovered double boiler may evaporate the water that would otherwise thin the mixture.

Type of heat: *Moist heat* is necessary for gelatinization to occur. *Dry heat* causes the starch to hydrolyze, forming shorter chain dextrans. Dry heat creates “browned” flour that imparts a slightly toasted flavor and brown color to a food mixture. This browning effect may be desired in many recipes.

Rate of heating: In general, the faster a starch–water dispersion is heated, the thicker it will be at an identical endpoint temperature.

It can be seen that many factors—many “if’s” must be controlled in the gelatinization process. For example, a desired three-dimensional starch structure forms IF gelatinization has occurred correctly, IF the starch is the correct type, IF

the concentration of starch is sufficient, IF the heat is correctly applied, IF inclusion of added substances is properly timed, and so forth!

The viscosity of a starch and water mixture is recorded on a moving graph as the mixture is tested and stirred (Fig. 4.4). The recording instrument portrays the thickness of starch mixtures during heating, gelatinization, and cooling. It may be used in order to show the effects of α -amylase on starch mixtures, or the thickness of various starches at different times and temperatures. Evidence of dextrinization may be seen.

Further discussion of specific times and temperatures of when various starches thicken or gel may be observed by reading data from a recording instrument or recording viscometer (Fig. 4.5). As illustrated in the graph in Fig. 4.4, *root* starches such as potato and tapioca, and *waxy cereal* starches thicken earlier and at lower temperatures than cereal starches.

Gelation or Setting of Gelatinized Starch Pastes During Cooling

Amylose

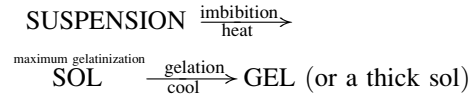
Further changes in the amylose component of starch pastes occur beyond the previously discussed process of gelatinization. During *cooling*, for example, the amylose “sets” and forms a *gel*—a process referred to as *gelation*. A gel forms a colloidal, elastic and solid, three-dimensional, two-phase system with a *solid* continuous phase of amylose polymers holding a *liquid* dispersed phase. This is in contrast to the *sol* it was beforehand.

The reason that the gel network forms is due to the fact that as the mixture cooled, energy is reduced. Subsequently, intermittent hydrogen cross-bonds formed among *amylose*, reassociating at random intervals of the amylose molecule, forming a *gel*.

Amylopectin

On the other hand, the highly branched *amylopectin* molecules do *not* readily form bonds or a gel.

Rather, amylopectin exhibits *less* tendency to re-associate or revert to a more crystalline structure than amylose. It remain a sol; however, it forms a *thick* sol upon cooling as shown below. This may be desirable in food items such as pie fillings.



Gels

Starches may be selected for use based on their gelling potential as identified in the following list:

Forms gel	Does not form gel
Cornstarch	Waxy cereals
Wheat starch	Tapioca
Wheat flour	

If gels are formed, mixtures are non-pourable and of high viscosity. It is significant to know that if an appropriate flour is utilized to yield a gel, gelling requires a quantity of two times the amount of flour as cornstarch because an equal amount of flour contains additional non-starch components, such as protein that will not gel.

Retrogradation

Retrogradation refers to the occurrence where starch reverts or retrogrades to a more crystalline structure upon cooling. Both amylose and amylopectin may participate in a textural change that makes them somewhat more “gritty” with time. Retrogradation is more likely to occur in a *high amylose* starch. This occurrence is noted in baked products that become “*stale*,” no longer “*fresh*” tasting or “*fresh*” handling (a “*fresh*” baked good indicates that the starch is still in existence as a gel form). It is also observed in leftover, long-grain rice. Due to its high amylose content, leftover rice gets hard.

Retrogradation Facts

Likely if gel has been formed improperly, the resulting amylose structures are fragile, readily losing entrapped water.

- The amylose retrogrades and recrystallizes.
- Retrogradation is likely when gel is exposed to the effects of freeze–thaw cycles, as the water is frozen and thawed. Water created from melted ice crystals is not able to reassociate with the starch, and water loss becomes apparent.

Included below are a few baking examples of retrogradation from the literature. They are used to better clarify the term.

“In baking, the starch present in bread dough and batters becomes gelatinized. During this process the starch goes from an ordered, crystalline state to a disordered, amorphous state. Upon cooling the disordered starch state begins to re-order (or retrograde), returning the starch back to its more rigid crystalline state, resulting in the firming of crumb texture in baked goods. Starch retrogradation is a time and temperature dependent process.” Available from: Tessier, J. Increasing Shelf-Life without Preservatives (Bakers’ Journal: July 2001)

“When the starch stays as a gel, a product is softer, and we say it is “fresh”. When the starch regains its crystalline form, the product becomes firmer, and we say it is “stale”. The technical term for this is starch retrogradation.” Available from: [Ingredients - Starch and Modified Starch](http://sci-toys.com/ingredients/starch.html) <http://sci-toys.com/ingredients/starch.html>

“Staling as a result of changes in the starch component (i.e., a change in the amylose and amylopectin starch molecules) of the bakery product is called starch retrogradation. Starch retrogradation begins as soon as baking is complete and the product begins to cool. Amylose retrogradation is mostly complete by the time the product has cooled to room temperature. Amylopectin retrogradation requires

more time than amylose retrogradation and as a result, is the primary factor resulting in staling. During the staling period, the amylopectin molecules revert back to their original firm state as rigid crystalline granules. As a result, the baked product loses moisture in the crumb, becoming firmer and less elastic.” Available from: Nadia Brunello-Rimando. Bakers’ Journal—Voice of the Canadian Baking Industry. May 2004. (Product and Process Development, *Consulting & Technical Services*) <http://www.gftc.ca/about-us>

Syneresis

Syneresis or “weeping” is water freed from a cooked, cooled starch gel. The process is a change following *gelatinization* and is caused by *gelation*. As a cooked, cooled starch gel stands, the gel ages, then further association of amylose occurs and the gel contracts, causing both water loss and shrinkage to become apparent. This is caused by retrogradation, and is the separation of a liquid from a gel, upon standing. The process is a change following *gelatinization* and is caused by *gelation*.

If cooled undisturbed, the gels remain strong, yet reassociation may be accompanied by the unacceptable water loss or *syneresis*. To control syneresis, modified starches (see “Modified Starches” section) or starches containing only non-gelling amylopectin are used in commercial products.

“Research has well established that the cooling conditions will impact the strength of the gel. Generally, if cooled too fast, the amylose will not have time to form the vital micelles necessary for the three dimensional structure. If cooled too slowly, the amylose fractions will have a chance to align too much and become too close together and the liquid portion will not be trapped in the micelles. In both instances there will be weeping and syneresis.” (Oregon State University) Available from: <http://food.oregonstate.edu/learn/starch.html>

Separating Agents and Lump Formation

Separating agents are used in food preparation in order to prevent lumps in a starch-thickened food item. A problem in the preparation of starch-thickened mixtures is the undesirable formation of lumps. Lumps are due to the unequal swelling or “clumping” together of individual starch granules. The granules must be allowed to swell independently; thus, it becomes important to “separate” the granules with a separating agent.

For product success, one of the three *separating agents* such as fat, cold water, and sugar must be used. They should be added to *just* the starch/flour ingredient in order to physically *separate* the grains *prior* to its addition to a recipe. The correct use of any of these agents produces a desirable smooth-textured mixture as opposed to a lumpy mixture.

Fat. *Fat* is a separating agent. When stirred into the flour, fat forms a film around the individual starch granule allowing each granule to swell independently of other granules. Thus, a *lump-free* sauce or gravy is obtained when liquid is added and cooking occurs. Oftentimes a *roux* is made—flour is browned and then separated by agitation with liquid fat during heating.

A roux may range in color from light brown to almost black (Cajun cooking). As a starch is heated and becomes darker, the starch progressively loses its thickening ability as it undergoes dextrinization from heating. An added benefit of adding flour to *hot* meat fat drippings is that α -amylase (which thins) is destroyed.

Cold water. *Cold water* may be used to physically separate starch granules. When mixed with insoluble starch, water puts starch granules in a suspension known as a “*slurry*.” The cold water–starch suspension is then slowly mixed into the hot liquid for thickening.

Cold water as a separating agent may be desirable if the product is to remain fat-free or sugar-free. *Hot* water is not a successful separating agent as hot water partially gelatinizes the starch.

Sugar. *Sugar* is a common separating agent used for a sweetened mixture. It is mixed with starch, prior to incorporation into the liquid,

so that starch granules remain physically separate to allow individual swelling without lump formation.

Once starch is separated, so that the granules do not “clump together,” forming lumps, the separated starch mixture is added to the other recipe ingredients. Sauces must be heated slowly and/or **stirred constantly** in order to be free of lumps. Extensive or harsh stirring after maximum gelatinization has occurred will rupture starch granules, causing the mixture to be thin.

CULINARY ALERT! Many cookbook recipes do not specify the use/proper use of a separating agent and the result is a mixture with lumps! The choice of which separating agent to use is dependent upon the desired end product—e.g., sweetened, fat-free.

Modified Starches

Natural starches may be *modified* chemically to produce physical changes that contribute to shelf stability, appearance, convenience, and performance in food preparation. Some “natural” starches are *not* modified chemically which may be a “plus” for concerned consumers and processors. Various examples of modified starches used in food manufacturing are described in the following text.

Pregelatinized starch is an instant starch that has been gelatinized and then dried. It subsequently swells in liquid without the application of heat. Pregelatinized starch appears in many foods, including instant pudding mixes.

Some properties of a pregelatinized starch include the following:

- Dispersible in cold water; it can thicken without heat being applied
- Can be cooked and dried, yet is able to reabsorb a lot of water in preparation without cooking the food (instant pudding)

- Undergoes irreversible change and *cannot* return to its original ungelatinized condition after treatment
- A greater weight of starch is required to thicken a liquid because some rupturing and loss of starch granule contents occurred during gelatinization and drying

Cold water-swelling (CWS) starch is an instant starch that remains as an *intact granule*. It offers convenience, stability, clarity, and texture. CWS starches may be gelling or non-gelling. They may be used in no-cook or cold-process salad dressings providing the thick, creamy mouthfeel in no-fat salad dressings.

Cross-linked starches are those that undergo a molecular reaction at selected hydroxyl (—OH) groups of two adjoining, intact, starch molecules. The purpose of cross-linking is to enable the starch to withstand such conditions as low pH, high shear, or high temperatures. The cross-linked starch becomes less fragile and more resistant to rupture than the original unmodified starch. Although it is more tolerant of *high* temperatures, it is *not* more tolerant of *cold* temperatures. These starches are used in many foods, especially acid food products such as pizza sauce or barbecue sauce because the modified starch is *more acid-resistant* than an unmodified starch. As a result of cross-linking, a starch swells less and is less thick.

Stabilized (substituted) starches are used in frozen foods and other foods stored at cold temperature in order to prevent gelling and subsequent syneresis. The main types of substitutions include hydroxypropylated, hydroxyethylated, and so forth. These starches prevent molecular associations and cause ionic repulsion. The stabilized starch produces pastes able to withstand several freeze–thaw cycles before syneresis occurs. This is value to the frozen food industry, and also to foods such as sauces and gravies stored at cold temperatures. Stabilized starches are *not* appropriate for foods that

require prolonged *heating*. However, starches may be modified by a combination of both cross-linking and stabilization treatments. Such modification ensures that the starches are acid-, heat-, and freeze–thaw-stable. Stabilized starches have a wide range of uses in food products.

Acid-modified starch is starch that is subject to treatment in an acid slurry. A raw starch and dilute acid are heated to temperatures less than the gelatinization temperature. Once the starch is mixed into a food product, it appears less viscous in *hot* form, although it forms a strong gel upon *cooling*. More about Modified Starches as follows: <http://food.oregonstate.edu/learn/starch.html>

Non-food uses for Modified Starches include glue in cardboard manufacture and glue on postage stamps

Waxy Starches

Waxy starches are derived from some natural strains of barley, corn, rice, and sorghum. They *do not* contain amylose, begin to thicken at *lower* temperatures, become *less* thick, and undergo *less* retrogradation than non-waxy varieties. *Waxy* cornstarch, for example, does not have the same gel forming properties as regular cornstarch. It contains *no* gel producing *amylose*, and only *amylopectin*.

- Waxy cornstarch—contains NO amylose, is all amylopectin, and does NOT gel
- Ordinary *cornstarch*—contains 27 % amylose and forms a gel
- *High amylose cornstarch*—contains 55 % amylose and forms a gel

Waxy varieties of starch are commonly used in the preparation of pie fillings to *thicken*, however, *not gel*. They may also be cross-linked for better function.

Starch Uses in Food Systems

Starches have many uses in food preparation and are very versatile and oftentimes inexpensive. They may be introduced into foods primarily because of their *thickening* ability. For example, pureed, cooked, or instant potatoes, or pureed cooked rice may be undetectable, however, useful as thickeners. A white sauce may be added during the preparation of a tomato and milk-based soup, in order to thicken and stabilize. It aids in the control of milk protein precipitation caused from the addition of tomato acid. Starch may also be useful as a water binder and gelling agent.

Another use of starch is as a *fat replacer* in food systems. Molecularly, the amylose chains form helical or spherical shapes, holding water and providing bulk. This confers the satisfying “mouthfeel” attributes on starch. Intermediate length polymers of D-glucose, called *maltodextrins*, are formed from the hydrolysis of starches such as tapioca, potato, and wheat. Maltodextrins simulate the viscosity and mouthfeel of fats/oils and are used to reduce the fat content of some foods.

With the use of ordinary cross-breeding procedures, new starches are being discovered that have various applications in food systems. Baking, microwave cakes, frozen sauces, fat replacers, breadings, snacks, and gelled candies are some of the uses of starch (American Maize-Products Company, Hammond, IN). For example, **pea starch** may offer an alternative to other modified starches used in the food industry as it provides a very high viscosity *immediately* upon agitation. It is available in pregelatinized form for use in cold processed products such as dessert creams, dressings, instant soups, and sauces (Feinkost Ingredient Company, Lodi, OH). Pea starch may also be environmentally friendly as a biodegradable food packing material introduced in landfill sites.

New food starches and their uses are continually being developed. Food starches are commercially manufactured and available

for use in products such as baked food, beverages, canned, frozen, and glassed foods, confections, dairy products, dry goods, meat products, and snack foods (National Starch and Chemical Company—Food Products Division, Bridgewater, NJ).

CULINARY ALERT! A starch chosen for use in food systems may involve a choice by habit, or convenience. Consumers may actually use less than the best because “it’s what mom always used, so I’ll use it too,” or “it’s here in the kitchen, so I’ll use it!”

Cooking with Starch

Several of the applications of cooking with starch appear below. Cooking with the appropriate starch, in the proper concentration, timing of addition, and so forth as previously discussed are factors crucial to the success of any starch-thickened product.

Appearance

The appearance of a cooked, cooled starch mixture is influenced by the choice of starch. For example, *cereal* starches in general produce *cloudy*, thickened mixture upon cooling. Within the group of cereals, *flour* produces a *more* cloudy thickened mixture than *cornstarch* because the wheat flour contains additional non-starch ingredients not present in cornstarch. A *clear gel* is produced using cornstarch.

A *clear, thickened mixture* is also produced by other non-gelling starch sources such as Arrowroot. Non-gelling may be a desirable feature of pie fillings.

Use of a Double Boiler

Cooking *over boiling water* (such as with a double boiler for household preparation) promotes

temperature control and a more even gelatinization than would occur with *direct heat* cooking. A disadvantage of this cooking method is that it requires cooking for a longer time period to reach the thickening stage than a direct heat cooking method.

Tempering

Tempering involves the technique of *slowly* adding small amounts of hot starch to eggs in a recipe, in order to gradually raise the temperature thus slowly exposing eggs to heat without the danger of coagulation. In this manner, the eggs do not curdle and produce an unacceptable consistency. To achieve the desired consistency and texture of a recipe containing hot starch *and* raw eggs (in sauces, cream puffs, etc.), the process of *tempering* is used.

White Sauce

White sauces have widespread applications in cooking. The *concentration* of starch used in a formulation varies. For example, a white sauce of flour, fat, and milk may be thickened to various consistencies, for croquettes, sauces, and so forth. The concentration of flour may be as follows:

White Sauces

Thin—1 tablespoon of flour/cup of liquid

Medium—2 tablespoons of flour/cup of liquid

Thick—3 tablespoons of flour/cup of liquid

Liquid

The use of liquid type varies in starch mixtures. *Water or fruit juice* is incorporated into some foods dictated by need for clarity or flavor. Milk is usually used in a starch-thickened sauce such as white sauce. Since milk easily curdles at high temperatures, it may be made less likely to curdle if it is first thickened with flour prior to recipe addition.

CULINARY ALERT! Flourless sauces are thickened by reduction of the stock/liquid. Portions of the starchy ingredients of a soup recipe may be saved out and pureed, and then added back to the soup in order to thicken and flavor it.

Nutritive Value of Starch

Nutritive value is provided by starches. Starches are a complex carbohydrate containing 4 cal/g, and traces of protein and fat. Short chain maltodextrins derived from the hydrolysis of starch may be used in foods to partially replace fat. Maltodextrins simulate the taste of fat, and offer less calories per gram than the 9 cal/g in fat.

Not all starch is capable of carrying calories or being digested. A “*resistant starch*” is dietary fiber, with an example being whole cooked beans. Resistant starches offer benefits to the colon, namely, “roughage.” Also, intestinal bacterial flora use fiber, producing vitamins such as vitamin K.

Whole grains that are *ground* to make flour are different than the whole grain from which they came. For example, they have a higher *glycemic index* than *unground* grains. This is due to the ease of absorbing the starch into the blood as sugars.

Special nutritional needs may require a dietary restriction of wheat that may lead to use of non-wheat starches for those individuals following gluten-free diets. Assorted alternatives to wheat are corn, potato, or rice starch. Packages of potato “flour” indicate on the finer print of the label that the contents are solely potato *starch* (Ener-G Foods, Inc., Seattle, WA). A gluten-free addition of starch or even fiber may be utilized in product development (Hazen 2012).

Safety of Starches

Starches are one of many white powders used in food handling and production operations. Proper storage, including separation from other dangerous

chemicals, is crucial. If used in bulk quantities, labeling of both the container and its lid (if removable) better assures safety of starches in the workplace.

CULINARY ALERT!

Conclusion

Starch is a plant polysaccharide that is the storage form of carbohydrate in roots, seeds, and tubers. It may be derived from cereals such as corn, wheat, rice, or oats, or legumes such as soybeans, or from vegetable roots and tubers such as potatoes or arrowroot. In its uncooked stage, starch is insoluble in water. As it is heated and undergoes gelatinization, factors such as acid, agitation, use of enzymes, fat, proteins, sugar, and temperature require control. A separating agent prevents lumps in a starch mixture.

The source of starch and its concentration determine the thickening, gelling, retrogradation, and clarity of the finished product. Flour and cornstarch may be used to form gels; waxy varieties of starch do not gel. Syneresis may occur as the cooked, cooled starch mixture ages. Modification of starch granules allows starches to be used successfully in a variety of food applications. Starch may be added to foods in order to provide thickening, or product stability, or potentially, to carry flavors.

Notes

Glossary

Adsorb Surface adherence of gas, liquids, or solids onto a solid.

Amylose Long, linear chain composed of thousands of glucose molecules joined by an α -1,4-glycosidic linkage.

Amylopectin Branched chains of glucose units joined by α -1,4 linkages, with α -1,6 branching occurring every 15–30 units.

Birefringence A Maltese cross appearance on each uncooked crystalline starch granule when viewed under a polarizing microscope due to light refraction in two directions.

Dextrin Glucose polymers; a product of the early stages of starch hydrolysis.

Gel Elastic solid formed upon cooling of a gelatinized starch paste; a two-phase system that contains a solid continuous phase and a liquid dispersed phase.

Gelatinization Starch granules take up water and swell irreversibly upon heating, and the organized granular pattern is disrupted.

Gelation Formation of a gel upon cooling of a gelatinized starch paste.

Granule Starch grain of long-chain glucose polymers in an organized pattern; granule shape is particular to each starch type.

Imbibition Starch granules taking up water and swelling as it is exposed to moist heat.

Maltodextrin Starch hydrolysis derivative that may be used to simulate fat in formulations.

Modified starch Specific chemical modification of natural starches to physically create properties that contribute to shelf stability, appearance, convenience, and performance in food preparation.

Retrogradation Reverting back, or reassociation of amylose as the gelatinized starch

once again forms a more crystalline structure upon cooling.

Separating agent Prevents lump formation in a starch mixture. Physically separates starch grains and allows their individual swelling.

Sol A two-phase system with a solid dispersed in a liquid continuous phase.

Spherical aggregate Open, porous starch granules with spaces that can be filled and used to transport materials such as flavor, essences, and other compounds.

Starch Carbohydrate made up of two molecules—amylose and amylopectin.

Suspension Large particles undissolved in the surrounding medium. Particles are too large to form a solution or a sol upon heating.

Syneresis “Weeping” or water loss from a cooked, cooled gel due to excessive retrogradation or improper gel formation.

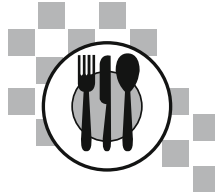
Viscosity Resistance to flow of a liquid when force is applied. A measure of how easily a liquid will flow. Thin liquids have a low viscosity. Thick liquids or gels have a high viscosity and flow slowly.

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Introduction

Pectins and gums are important polysaccharides in foods because of their functional properties. They are widely used as gelling agents, thickeners, and stabilizers. They are constituents of plant tissue and are large, complex molecules whose exact nature is not certain. However, enough is known to understand some of their properties and to make use of their functional properties to produce convenience and special texture foods.

To identify a few, pectic acid is found in overripe fruit. Some recognizable gums are seed gums such as guar gum and locust bean gum, and common seaweed polysaccharides including carrageenan and agar.

Pectic Substances

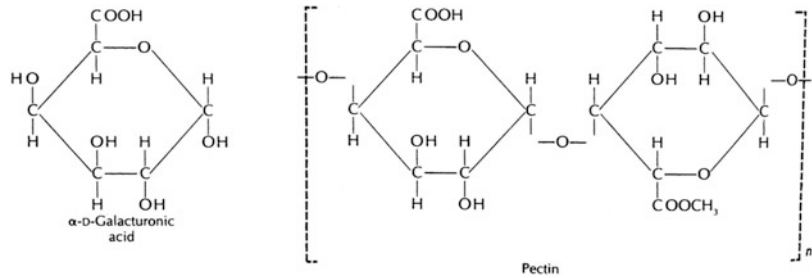
Pectic substances including protopectin, pectinic acid, and pectic acid are an important constituent of plant tissue and are found mainly in the primary cell wall. They also occur between cell walls, where they act as intercellular cement. Although their exact nature is not clear, they can be considered as linear polymers of D-galacturonic acid joined by α -1,4-glycosidic linkages, as shown in Fig. 5.1. Some of the acid or carboxyl (COOH) groups along the chain are esterified with methanol (CH₃OH) as shown.

Each glycosidic linkage is a **cross-planar** bond, because it is formed by reaction of one hydroxyl group located above the plane of the first ring with another hydroxyl group located below the plane of the second ring. The configuration of these bonds causes twisting of the molecule, and the resulting polymer can be likened to a twisted ribbon. Cross-planar bonds are not readily digested in the human digestive tract, and so pectins are classified as soluble fiber.

Pectic substances may be grouped into one of the three categories depending on the number of methyl ester groups attached to the polymer. **Protopectin** is found in immature fruits, and is a high-molecular weight methylated galacturonic acid polymer. It is insoluble in water yet can be converted to water-dispersible pectin by heating in boiling water. It cannot form gels.

Pectinic acid is a methylated form of galacturonic acid that is formed by enzymatic hydrolysis of protopectin as a fruit ripens. High-molecular weight pectinic acids are known as pectins. Pectinic acids are dispersible in water and can form gels. **Pectic acid** is a shorter-chain derivative of pectinic acid that is formed as fruit overripens. Enzymes, such as polygalacturonase and pectinesterase, cause depolymerization and demethylation of the pectinic acid, respectively. Complete demethylation yields pectic acid, which is incapable of gel formation.

Fig. 5.1 Basic structure of pectic substances



Pectic Substances

Protopectin—methylated galacturonic acid polymer found in immature fruits.

Pectinic acid—methylated galacturonic acid polymer; includes pectins.

Pectic acid—short-chain demethylated derivative of pectinic acid found in over-ripe fruits.

Pectins

Pectins are high-molecular weight pectinic acids and are dispersible in water. Some of the carboxyl groups along the galacturonic acid chain are esterified with methanol. The degree of esterification in unmodified pectins ranges from about 60 % in apple pulp to about 10 % in strawberries. (Pectins can be deliberately deesterified during extraction or processing.) According to the degree of esterification, pectins are classified as *high-methoxyl* or *low-methoxyl* pectins. The two groups have different properties and gel under different conditions.

Low-methoxyl pectins. Low-methoxyl pectins contain mostly free carboxyl groups. In fact, only 20–40 % of the carboxyl groups are esterified. Therefore, most of them are available to form cross-links with divalent ions such as calcium, as shown in Fig. 5.2.

If sufficient cross-links are formed, a three-dimensional network can be obtained that traps liquid, forming a gel. Low-methoxyl pectins can, thus, form gels in the presence of divalent ions without the need for sugar or acid.

High-methoxyl pectins. High-methoxyl pectins contain a high proportion (usually

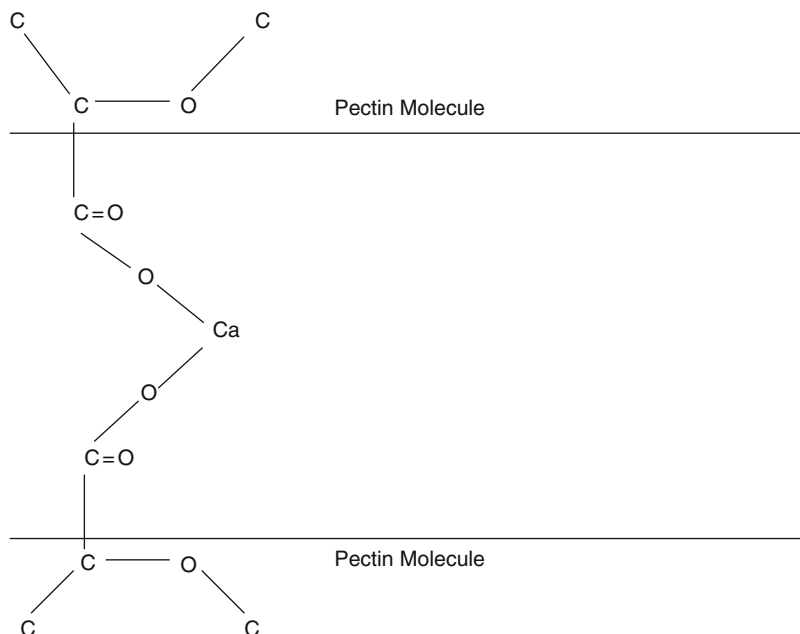
50–58 %) of esterified carboxyl groups. Most of the acid groups are, therefore, not available to form cross-links with divalent ions, so these pectins do not form gels. However, they can be made to gel with the addition of sugar and acid. It is the high-methoxyl pectins that are commonly used to form pectin jellies.

Pectin Gel Formation

A pectin gel consists mainly of water held in a three-dimensional network of pectin molecules. Pectin is dispersible in water and forms a *sol* (solid dispersed in liquid continuous phase), although under the right conditions, it can be converted into a *gel* (liquid dispersed in solid continuous phase). This occurs when the pectin molecules interact with each other at specific points. It is not easy to form pectin gels; it requires a delicate balance of pectin, water, sugar, and acid.

Pectin is hydrophilic (water loving) due to the large number of polar hydroxyl groups and charged carboxyl groups on the molecule. When pectin is dispersed in *water*, some of the acid groups ionize, and water binds to both the charged and polar groups on the molecules. The negative charge on the pectin molecules, coupled with their attraction for water, keeps them apart so that they form a stable sol.

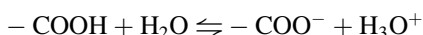
To form a gel, the forces keeping the pectin molecules apart must be reduced so that they can interact with each other at specific points, trapping water within the resulting three-dimensional network. In other words, the attraction of the pectin molecules for water must be *decreased* and the attraction of the pectin molecules for

Fig. 5.2 Cross-links in low-methoxyl pectin

each other must be *increased*. This can be achieved by addition of sugar and acid.

Sugar competes for water, thus making less water available to associate with the pectin molecules. This reduces the attractive forces between the pectin and water molecules.

Acid adds hydrogen ions, reducing the pH. (The pH must be below 3.5 for a gel to form.) Carboxylic acids contain a **carboxyl group** (COOH), are weak acids, and are not fully ionized in solution; the un-ionized form of the acid exists in equilibrium with the ionized form.



When hydrogen ions are added, they react with some of the ionized carboxyl groups to form undissociated acid groups. In other words, the equilibrium is shifted to the left, and more of the carboxylic acid is present in the un-ionized form. Thus, when hydrogen ions are added to pectin, the ionization of the acid groups is depressed and the charge on the pectin molecules is reduced. As a result, the pectin molecules no longer repel each other.

In fact, there is an attractive force between the molecules and they align and interact at specific regions along each polymer chain to form a three-dimensional network. These regions of interaction are called **junction zones**, shown diagrammatically in Fig. 5.3. However, there are also regions of the pectin chains that are not involved in junction zones because they are unable to interact with each other. These regions form pockets or spaces between the junction zones that are able to entrap water. Hence, a gel is formed, with water trapped in the pockets of the three-dimensional pectin network.

Exactly how the junction zones form is not certain, although hydrogen bonds are thought to play an important role. The **steric fit** of the molecules (in other words, their ability to fit together in space) is also important. Pectin molecules contain minor components such as rhamnose and other neutral sugars that are bound to the main galacturonic acid chain by 1-2-glycosidic links. These sugars cause branches or kinks in the molecules and make it difficult for them to align and interact to form junction zones. However, there are regions of the pectin chains that do not contain these neutral sugars and it is

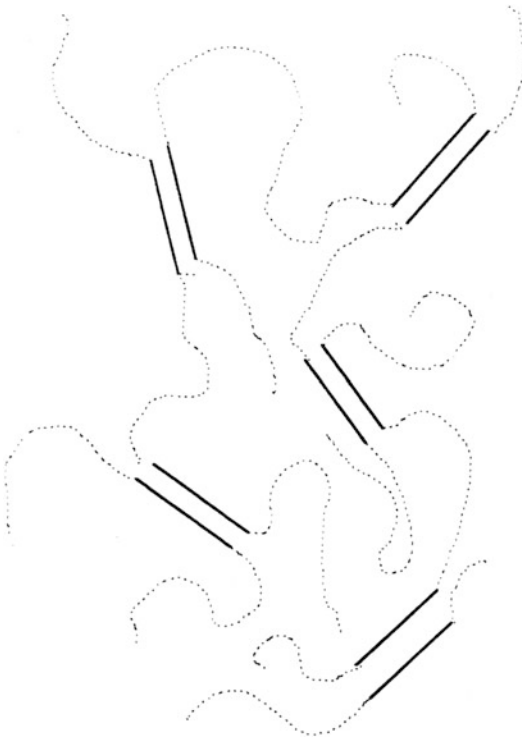


Fig. 5.3 Junction zones in a pectin gel. Generalized two-dimensional view. Regions of the polymer chain involved in junction zones are shown as—. The other regions of the chain are shown as—. Water is entrapped in the spaces between the chains. Adapted from Coultate (2009)

these regions that are thought to form the junction zones.

High-methoxyl pectins form gels in this way. Low-methoxyl pectins require divalent ions to gel, and intermediate pectins require sugar, acid, and divalent ions to gel.

Pectin Sources

Pectins with a high-molecular weight and a high proportion of methyl ester groups have the best jelly-forming ability. The pectin content of fruits is variable and depends not only on the type of fruit but also on its maturity or ripeness. If jellies or jams are made at home, it is best to add commercial pectin to ensure that there is sufficient pectin to form a gel. Purified pectin is made from apple cores and

skins (apple pomace) and from the white inner skin (albedo) of citrus fruits. It is available in either liquid or granular form. The granular products have a longer shelf life than the liquids. Low-methoxyl pectin can be obtained by demethylating pectin with enzymes, acid, or alkali until it is 20–40 % esterified (Glicksman 1982). Since these pectins gel with divalent ions and need no sugar, they can be used commercially for the production of low-calorie jams, jellies, or desserts. They have also been introduced to the retail market so that such low-calorie products may be made at home.

Pectin Gel Formation

In a pectin sol

- **Water** binds to ionic and polar groups on pectin.
- **Pectin** molecules are negatively charged and hydrated; therefore, they do not interact with each other.

To form a pectin gel

- Attraction of pectin molecules for water must be decreased.
- Attraction of pectin molecules for each other must be increased.

This is achieved with

- **Sugar**
 - Competes for water.
 - Decreases pectin–water attraction.
- **Acid**
 - Adds hydrogen ions.
 - Depresses ionization of pectin.
 - Reduces the charge on the pectin molecules.
 - Increases pectin–pectin attraction.
- **Pectin**
 - Interacts at junction zones forming a three-dimensional network.
 - Pectin becomes the continuous phase.
- **Water**
 - Is trapped in pockets within the gel network.
 - Water becomes the disperse phase.

Some Principles of Making Jelly

This book does not attempt to describe the practical aspect of making jellies. For such information, the reader is referred to consumer information publications, or to books by authors such as Charley (Charley and Weaver 1998) or Penfield and Campbell (Coultrate 2009). The intention is to highlight some of the more important scientific principles of jelly-making.

To make jelly, fruit juice (which is a source of water and acid), pectin, and sucrose are combined in a suitable pan and heated until the mixture boils. The temperature and boiling time are monitored, and boiling is continued until the desired temperature is reached.

As boiling continues, water evaporates, the concentration of sucrose increases, and the boiling point of the jelly also increases. Therefore, the boiling point can be used as an index of sucrose concentration. By measuring the temperature of the boiling jelly, it can be determined when sufficient water has been removed to give the desired sucrose concentration in the final jelly.

However, all solutes increase the boiling point of water, so it is important to allow for the effect of any additional ingredients on the boiling point; a pure sucrose solution may boil at a lower temperature than a jelly mix containing the same concentration of sucrose. In other words, a boiling jelly may contain less sucrose than expected if the effects of the additional ingredients on the boiling point are not taken into account. This could result in a runny or weak gel.

It is important to control the boiling time, not just the temperature of the boiling jelly, because chemical reactions occur in the presence of heat and acid that need to be controlled to maintain gel quality. Glycosidic links are hydrolyzed in the presence of heat and acid. Therefore, depolymerization of pectin will occur if the boiling time is too long. This will result in loss of gelling power and the gel may not set.

During the boiling process, sucrose is converted to invert sugar, and the presence of invert sugar in the jelly prevents crystallization of sucrose on storage over a long period. A short boiling time may not allow formation of sufficient invert sugar to inhibit sucrose crystallization over time, especially if the jelly is stored at refrigeration temperatures.

Boiling Time

- If too long—depolymerization of pectin occurs, and the gel may not set.
- If too short—insufficient invert sugar may be formed, and crystallization of sucrose may occur.

It has already been mentioned that a commercial pectin should be used in addition to the fruit, because the quality of pectin in the fruit varies. An overripe fruit is deficient in pectin, because demethylation and depolymerization occur as the fruit ages. Hydrolysis of only a few glycosidic bonds causes a marked drop in viscosity and gelling power and will produce a weak gel.

Gums

Gums are a group of complex hydrophilic carbohydrates containing thousands of monosaccharide units. Galactose is the most common monosaccharide found in gums; glucose is usually absent. Gums are often referred to as *hydrocolloids*, because of their affinity for water and their size; when added to water, they form stable aqueous colloidal dispersions or sols. The molecules are highly branched, and as a result most gums are unable to form gels. However, they are able to trap or bind large amounts of water within their branches. Aqueous dispersions therefore tend to be very viscous, because it is difficult for the molecules to move around freely without becoming entangled with each other.

Main Characteristics of Gums

- Larger highly branched hydrophilic polymers
- Rich in galactose
- Hydrocolloids
- Form viscous solutions
- Most do not gel if used alone
- Seaweed polysaccharides form gels

Gums are classified as soluble fiber because they undergo little digestion and absorption in the body. Therefore, they supply relatively few calories to the diet, as compared with digestible carbohydrates such as starch.

Gums are common in a wide range of food products, including salad dressings, sauces, soups, yogurt, canned evaporated milk, ice cream and other dairy products, baked goods, meat products, and fried foods. They are used as thickening agents in food products, replacing starch. They are also used to assist in the stabilization of emulsions and to maintain the smooth texture of ice cream and other frozen desserts. They are common in reduced fat products, because they are able to increase viscosity and help to replace the texture and mouthfeel that was contributed by the fat.

Gums are obtained from plants, and can be separated into five categories: seed gums, plant exudates, microbial exudates, seaweed extracts, and synthetic gums derived from cellulose.

Seed Gums

The seed gums include guar and locust bean gums. These gums are branched polymers containing only mannose and galactose. Guar gum contains a mannose/galactose ratio of 2:1, whereas the ratio is 4:1 in locust bean gum. Guar gum is soluble in cold water, whereas locust bean gum must be dispersed in hot water. Neither gum forms a gel when used alone. However, they may be used synergistically with other gums to form gels.

Guar gum forms gels with carrageenan and guar gum. It is used to stabilize ice cream, and it is also found in sauces, soups, and salad dressings.

The presence of guar gum in the intestine seems to retard the digestion and absorption of carbohydrates and slow absorption of glucose into the bloodstream. Use of guar gum in foods may, therefore, be useful in treating mild cases of diabetes (Penfield and Campbell 1990).

Locust bean gum is typically used as a stabilizer in dairy and processed meat products. It may also be used synergistically with xanthan gum to form gels.

Plant Exudates

The plant exudates include gum arabic, which comes from the acacia tree, and gum tragacanth. These are complex, highly branched polysaccharides. Gum arabic is highly soluble in cold water, and is used to stabilize emulsions and to control crystal size in ices and glazes. Gum tragacanth forms very viscous sols, and is used to impart a creamy texture to food products. It is also used to suspend particles, and acts as a stabilizer in products such as salad dressings, ice cream, and confections.

Categories of Gums

- **Seed gums:** guar gum, locust bean gum
- **Plant exudates:** gum arabic, gum tragacanth
- **Microbial exudates:** xanthan, gellan, dextran
- **Seaweed polysaccharides:** alginates, carrageenan, agar
- **Synthetic gums:** microcrystalline cellulose, carboxymethyl cellulose, methyl cellulose

Microbial Exudates

Xanthan gum, gellan gum, dextran, and curdlan are all gums produced using fermentation by

microorganisms. Of these, *xanthan* is the most common. Xanthan forms viscous sols that are stable over a wide range of pH and temperature. It does not form a gel, except when used in combination with locust bean gum. It is used in a wide range of products as a thickener and stabilizer and suspending agent. For example, most salad dressings contain xanthan gum. Xanthan gum is extremely versatile and relatively inexpensive, which makes its presence almost ubiquitous in thickened food products.

Seaweed Polysaccharides

The *seaweed polysaccharides* include the agars, alginates, and carrageenans. Unlike most other gums, they are able to form gels under certain conditions.

Carrageenan is obtained from red seaweeds, and especially from Irish moss. It occurs as three main fractions, known as kappa-, iota-, and lambda-carrageenan. Each is a galactose polymer containing varying amounts of negatively charged sulfate esters. Kappa-carrageenan contains the smallest number of sulfate esters, and is therefore the least negatively charged. It is able to form strong gels with potassium ions. Lambda-carrageenan contains the largest number of sulfate groups, and is too highly charged to form a gel. Iota-carrageenan forms gels with calcium ions.

The carrageenan fractions are generally used in combination. Several different formulations are available, containing different amounts of the individual fractions, and food processors are able to choose formulations that best fit their needs.

The carrageenans are used to stabilize milk products such as ice cream, processed cheese, canned evaporated milk, and chocolate milk, because of their ability to interact with proteins. The carrageenans may also be used with other gums, because of their ability to cross-link with them (see more in Food Additives chapter).

Agar is also obtained from red seaweeds. It is noted for its strong, transparent, heat-reversible gels; that is, agar gels melt on heating

and re-form when cooled again. Agar contains two fractions—agarose and agaropectin, both of which are polymers of β -D- and α -L-galactose. Agaropectin also contains sulfate esters.

The **alginates** are obtained from brown seaweeds. They contain mainly D-mannuronic acid and L-guluronic acid, and they form gels in the presence of calcium ions. Calcium alginate gels do not melt below the boiling point of water; thus, they can be used to make specialized food products. Fruit purees can be mixed with sodium alginate and then treated with a calcium-containing solution to make reconstituted fruit. For example, if large drops of cherry/alginate puree are added to a calcium solution, convincing synthetic cherries are formed. Reconstituted apple and apricot pieces for pie fillings can also be made by rapidly mixing the sodium alginate/fruit puree with a calcium solution and molding the gel into suitable shapes.

Functional Roles of Gums

Gums may be used to perform one or more of the roles in food products.

- **Thickeners**—salad dressings, sauces, soups, beverages
- **Stabilizers**—ice creams, icings, emulsified products
- **Control crystal size**—candies
- **Suspending agents**—salad dressings
- **Gelling agents**—fruit pieces, cheese analogs, vegan jellies
- **Coating agents**—batters for deep-fried foods
- **Fat replacers**—low-fat salad dressings, ice creams, desserts
- **Starch replacers**—baked goods, soups, sauces
- **Bulking agents**—low-fat foods
- **Source of fiber**—beverages, soups, baked goods

CULINARY ALERT! Vegan jellies can be made using products that contain agar, carrageenan, and/or other gums such as locust bean gum and xanthan gum in place of gelatin.

(One such product is *Lieber's Unflavored Jel*, which contains both carrageenan and locust bean gum, and is available from <http://www.VeganEssentials.com>.)

Synthetic Gums

Cellulose is an essential component of all plant cell walls. It is insoluble in water and cannot be digested by man, and so it is not a source of energy for the body. It is classified as insoluble fiber.

The polymer contains at least 3,000 glucose molecules joined by β -1,4-glycosidic linkages. Long cellulose chains may be held together in bundles forming fibers, as in the stringy parts of celery.

Synthetic derivatives of cellulose are used in foods as *nonmetabolizable* bulking agents, binders, and thickeners. *Microcrystalline cellulose*, known commercially as Avicel (FMC Corp.), is used as a bulking agent in low-calorie foods. It is produced by hydrolysis of cellulose with acid. *Carboxymethyl cellulose* (CMC) and *methyl cellulose* (MC) are alkali-modified forms of cellulose. The former is the most common, and it is often called simply *cellulose gum*. It functions mainly to increase the viscosity of foods. It is used as a binder and thickener in pie fillings and puddings; it also retards ice crystal growth in ice cream and the growth of sugar crystals in confections and syrups.

In dietetic foods, it can be used to provide the bulk, body, and mouthfeel that would normally be supplied by sucrose. *Methyl cellulose* forms gels when cold dispersions are heated. It is used to coat foods prior to deep fat frying, in order to limit absorption of fat. Two other forms of modified cellulose include *hydroxypropyl cellulose* and *hydroxypropylmethyl cellulose*. These are also used as batters for coating fried foods.

As well, there may be a synergistic effect of using various gums together. This is most likely the case when more than one gum name appears on a food label!

Conclusion

Pectins and seaweed polysaccharides are useful for various food products because of their gelling ability. In general, gums are important because they form very viscous solutions, but most do not gel. All these carbohydrates are important to the food industry because of their functional properties and their ability to produce foods with special textures. Used in a wide range of food products, as gelling agents, thickeners, and stabilizers, their availability has increased the choice and quality of many convenience foods. Synthetic derivatives of cellulose are important as nonmetabolizable bulking agents, thickeners, and stabilizers in a wide range of calorie-reduced foods.

Notes

CULINARY ALERT!

Glossary

Carboxyl group COOH group; weak acid group that is partially ionized in solution.

Carboxymethyl cellulose (CMC) Synthetic derivative of cellulose used as a bulking agent in foods. Also known as cellulose gum.

Cellulose Glucose polymer joined by β -1,4-glycosidic linkages; cannot be digested by humans, and so provides dietary fiber.

Cross-planar bond Formed when the hydroxyl groups on the carbon atoms involved in the formation of a glycosidic bond are oriented on opposite faces of the sugar rings. Cross-planar bonds occur in pectin and cellulose. They are not digested in the human digestive system.

Gel Two-phase system with a solid continuous phase and a liquid dispersed phase.

Gums Complex, hydrophilic carbohydrates that are highly branched and form very viscous solutions; most gums do not gel.

High-methoxyl pectin Pectin with 50–58 % of the carboxyl groups esterified with methanol.

Hydrocolloid Large molecule with a high affinity for water that forms a stable aqueous colloidal dispersion or sol. Starches, pectins, and gums are all hydrocolloids.

Junction zone Specific region where two molecules such as pectin align and interact, probably by hydrogen bonds; important in gel formation.

Low-methoxyl pectin Pectin with 20–40 % of the carboxyl groups esterified with methanol.

Pectic acid Shorter-chain derivative of pectinic acid found in overripe fruits; demethylated; incapable of forming a gel.

Pectic substances Include protopectin, pectinic acids, and pectic acids.

Pectin High-molecular-weight pectinic acid; methylated α -D-galacturonic acid polymer.

Pectinic acid Methylated α -D-galacturonic acid polymer; includes pectins; can form a gel.

Protopectin Insoluble material found in immature fruits; high-molecular weight methylated galacturonic acid polymer; cannot form a gel.

Seaweed polysaccharides Complex polysaccharides that are capable of forming gels; examples include alginates, carrageenan, and agar; used as thickeners and stabilizers in food.

Sol or dispersion Two-phase system with a solid dispersed phase and a liquid continuous phase.

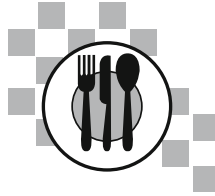
Steric fit Ability of molecules to come close enough to each other in space to interact (or fit together).

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Introduction

Throughout the world, there is a great variety of types and amounts of grain products that are selected to be consumed by individuals. The World Health Organization (WHO) and many countries including the United States stress the *nutritional* importance of grains as a foundation of a good diet.

From a *culinary* point of view, consumers see a great variety of grains included in menu offerings—from soups and salads to desserts. Grain consumption has risen substantially in popularity due in part to a committed number of Americans making more nutritious food selections. Specific grain choices may be based on food intolerances or allergies.

In this chapter the physical and chemical properties of grains are addressed. The variety of cereals, milling, type of flours used in bread making, pasta products, safety, and nutritional value are presented. Further discussion of quick breads, yeast breads, the functions of various added ingredients, and details of gluten appear in the chapter on Baked Products.

Cereals Definition

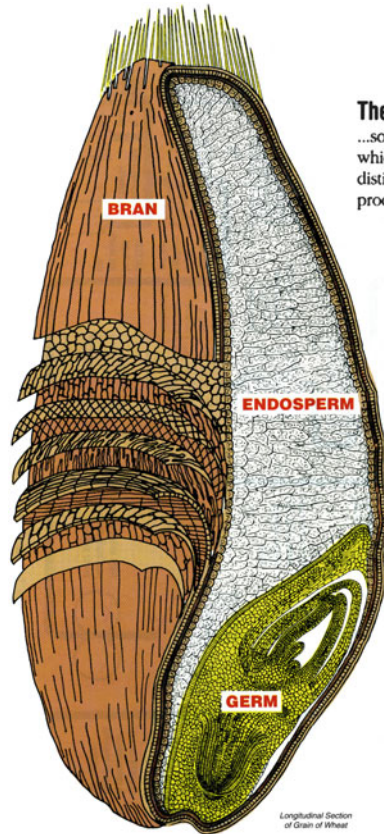
Cereal is a cultivated *grass*, such as wheat, corn, rice, and oats, which produces an edible *seed* (grain or fruit). By definition, *cereal* comprises

all the cereal products prepared from grain, not merely cold, sweetened, boxed breakfast cereal! Depending on the composition, the cereal crops may be *processed into various items* such as the following:

- **Bread**, using flour or meal from various grains (Chap. 15)
- **Cereal**, ready-to-eat, or cooked breakfast cereal varieties; such as oatmeal
- **Oil**, from germ processing (Chap. 12)
- **Pasta**, a dried paste of various flours (and perhaps legumes, herbs, and spices)
- **Starch**, from the starchy component of endosperm (Chap. 4)

When stored *properly*, and thus protected from adverse environmental impact, insect, and animal pests, grains are extremely resistant to deterioration during storage, especially when compared to the perishable dairy, eggs, meats, or fruit and vegetable crops. Grains are utilized extensively in developing and *less* affluent countries where animal products are either not available or not used. In *more* affluent countries, many varieties of grains and whole grains, processed ready-to-eat (r-t-e) breakfast cereals, cereal bars, and so forth are routinely consumed along with animal products.

Fig. 6.1 Structure of a wheat kernel (*Source:* Wheat Foods Council)



The Kernel of Wheat

...sometimes called the wheat berry, the kernel is the seed from which the wheat plant grows. Each tiny seed contains three distinct parts that are separated during the milling process to produce flour.

Endosperm

...about 83 percent of the kernel weight and the source of white flour. The endosperm contains the greatest share of protein, carbohydrates and iron, as well as the major B-vitamins, such as riboflavin, niacin, and thiamine. It is also a source of soluble fiber.

Bran

...about 14½ percent of the kernel weight. Bran is included in whole wheat flour and can also be bought separately. The bran contains a small amount of protein, large quantities of the three major B-vitamins, trace minerals, and dietary fiber — primarily insoluble.

Germ

...about 2½ percent of the kernel weight. The germ is the embryo or sprouting section of the seed, often separated from flour in milling because the fat content (10 percent) limits flour's shelf-life. The germ contains minimal quantities of high quality protein and a greater share of B-complex vitamins and trace minerals. Wheat germ can be purchased separately and is part of whole wheat flour.

Structure of Cereal Grains

The structure is similar in all grains. Each kernel of grain is composed of three parts: the *germ*, *endosperm*, and *bran*, and if *all* are present in a grain, it is a *whole grain*, such as whole wheat. When the bran and/or germ of the seed are removed or separated from the kernel in milling, a product is no longer “whole grain,” however *refined* (Fig. 6.1). Most likely, these two terms are familiar to the reader. It is recommended by the USDA to “make half your grains whole.” That advice also appears on many grain-based food products available to the consumer, such as whole grain crackers and cereals. Actual whole grain content is made available on Nutrition Facts and the Ingredients labels.

The *germ*, or embryo, is the *inner* portion of the kernel—located on the lower end. It composes approximately 2.5 % of the seed and is where sprouting begins as the new plant grows. The germ is the kernel component with the highest percent lipid, containing 6–10 % lipid. Rancidity may result from either the lipoxidase *enzyme*, or *non-enzymatic* oxidative rancidity.

Due to this possibility of rancidity, a whole grain product may either undergo germ removal or include antioxidants such as BHA or BHT (see Additives, Chap. 18). The germ contains approximately 8 % of the kernel's protein and most of the thiamin.

Another structural part of the kernel is the *endosperm*. It represents the greatest percentage of the kernel and is primarily starch, held as part of a protein matrix, with an exact composition that differs among grain types and varieties.

Regardless of the grain type, wheat, corn, or another grain, the endosperm is the seed component *lowest* in fat, containing *less* than the *germ*, with up to only 1.5 % of the lipid of the seed. It is also *lower* in fiber than the *bran*. The endosperm makes up approximately 83 % of the seed and has approximately 70–75 % of the protein of the kernel.

Specifically regarding wheat—certain varieties or types of wheat may be carefully specified for use in various food products in order to ensure success in baking or cooking. Wheat bakes and functions differently depending on the type of wheat that is utilized. For example, wheat may be a *soft* or *hard* type, with the soft wheat variety containing more starch and less protein than hard wheat. The composition makes a difference as shown later in this chapter.

The *third* major component of a grain in addition to the germ and endosperm is the *bran*. It is the layered, outer coat of a kernel and consists of an *outside* pericarp layer, offering protection to the seed, and an *inside* layer that includes the seed coat. The bran is often removed by abrasion or polishing in the milling process and may be used in many foods or animal feed. It is approximately 14.5 % of the seed and contains 19 % of the protein, 3–5 % lipid, and minerals such as iron.

Bran provides *cellulose* and *hemicellulose* that are both fiber or “roughage” in the diet. Yet, functionally, the individual bran may differ among grain types and varieties. For example, *wheat bran* includes an *insoluble fiber* that functions chiefly as a stool softener. *Oat bran* is a soluble fiber that functions among other ways, to reduce serum cholesterol.

If wheat is devoid of the bran, and germ, only the endosperm remains, and that is the component used in making white bread.

Composition of Cereal Grains

In *structural* composition, the various grains each contain three parts and thus the grains are similar; however, they vary in their *nutrient* composition, with each grain containing different amounts of

carbohydrate, fat, protein, water, vitamins, and minerals (Tables 6.1 and 6.2). The main nutrient component of cereal grains is **carbohydrate**, which makes up 79–83 % of the dry matter of grain. It exists predominantly as starch, with fiber especially cellulose and hemicellulose, composing approximately 6 % of the grain.

Lipid (fats and oil) makes up approximately 1–7 % of a kernel, depending on the grain. For example, wheat, rice, corn, rye, and barley contain 1–2 % lipid; oats contain 4–7 %. The lipid is 72–85 % unsaturated fatty acids—primarily, oleic acid and linoleic acid.

Protein composes 7–14 % of the grain, depending on the grain. Cereals are low in the amino acids tryptophan and methionine, and although potential breeding may produce cereals higher in the amino acid *lysine*, it remains the *limiting* amino acid in cereals.

Grain consumption provides half of the protein consumed worldwide. However, in comparison to animal foods such as milk, meats, or eggs, grains from plants do *not* include all the essential amino acids contained in animal protein. Grains are not complete proteins. In fact, the protein is of *low biological value*, and therefore, less efficient in supporting body needs.

Combining the various food sources of protein is common in cultures throughout the world. For example, the preparation of traditional dishes combines the lower biological value grains with *legumes* or *nuts* and *seeds* to provide the needed amino acids to yield a *complete* dietary protein. In particular, combining beans with rice, or beans with cornbread; combining tofu and vegetables, or tofu and cashews, or eating chickpeas and sesame seed paste (tahini) known as hummus, or peanut butter on whole wheat bread, and so forth are put together (eaten in combinations) creating complete proteins. (Botanically, each of these grains, legumes, nuts, and seeds are *fruits* of a plant.)

CULINARY ALERT! All “flour” used in a recipe is not created equal. High protein or “hard” flour absorbs more water than low protein “soft” flour. Therefore, finished products using assorted “flour” will differ. The recipe

Table 6.1 Typical percent composition of common cereal grains (100 g)

Grain	Carbohydrate	Fat	Protein	Fiber	Water
Wheat flour	71.0	2.0	13.3	2.3	12.0
Rice	80.4	0.4	6.7	0.3	12.0
Corn meal	78.4	1.2	7.9	0.6	12.0
Oats, rolled	68.2	7.4	14.2	1.2	8.3
Rye flour	74.8	1.7	11.4	1.0	11.1
Barley	78.9	Trace	10.4	0.4	10.0
Non-cereal flours					
Buckwheat flour	72.1	2.5	11.8	1.4	12.1
Soybean flour, defatted	38.1	0.9	47.0	2.3	8.0

Source: Wheat Flour Institute

Table 6.2 Vitamin, mineral, and fiber content of wheat flours (100 g)

Flour	Thiamin B ₁ (mg)	Riboflavin B ₂ (mg)	Niacin B ₃ (mg)	Iron (mg)	Fiber (g)
Whole wheat flour (whole grain)	0.66	0.14	5.2	4.3	2.8
Enriched flour (enriched)	0.67	0.43	5.9	3.6	0.3
White flour (refined)	0.07	0.06	1.0	0.9	0.3

Source: Wheat Flour Institute

must specify flour type and users must plan usage accordingly in order to ensure product success.

Significant proteins in some grains such as wheat, rye, and barley are *gliadin*, *secalin*, and *hoirdein*, respectively. To the extent that these proteins are present, flour has “**gluten-forming potential.**” Then, with subsequent and sufficient hydration and manipulation these proteins form a gummy, elastic *gluten* structure (Chap. 15). *Wheat* contains both gliadin and glutenin proteins that contribute desirable strength and extensibility to the yeast dough, in bread making. Other flours without these two proteins cannot rise sufficiently, even with the use of yeast because there are no gluten stands to trap the yeasts’ air and gasses.

CULINARY ALERT! Knowing that gluten may be an allergen, some individuals must follow a gluten-free diet.

CULINARY ALERT! Gluten-forming flour is high protein. Yeast is a good leaven to slowly fill the gluten structure as it readily stretches. Non-gluten-forming flour contains less protein. Baking powder and baking soda that bubble up

immediately are good leavens for non-gluten-forming flour.

An additional protein, the enzyme α -amylase, is naturally present in grains and promotes dextrinization of starch molecules to shorter-chain polymers, as well as the sugars maltose and glucose. The action of α -amylase may thin starch mixtures or be detrimental to the bread-making industry, yet it is often added in the form of malt so that there is sugar to feed yeast.

In this section on proteins in grains, we have seen that worldwide, grain consumption is common, as is one grain used in combination with other grains.

For a number of nations, just *having* grains is an important issue. For other more affluent and mobile nations, a Baker may *have* sufficient grain and have concerns instead about the *baking* properties of the grain. In this latter case, for example, the chef might be concerned, not about shortages, though rather about functionality of the flour. The fact is that wheat flours *high* in protein absorb a lot of water, while *low* protein flours do not absorb much. This can mean a dry or a soupy mixture, and perhaps unsatisfactory finished foods. Armed with a knowledge of flour differences, an experienced

baker knows that recipes that work for them in one region of the country may not work in another, and that all "flour" is not created equal!

Vitamins present in cereals are predominantly the B vitamins—thiamin (B₁), riboflavin (B₂), and niacin (B₃). These vitamins may be lost in the milling process and so are added back through the process of *enrichment*. Today, there is less prevalence of the once deadly diseases beriberi and pellagra, due to cereal enrichment with thiamin and niacin, respectively (Table 6.2). Whole grain products contain some fat-soluble vitamins in the germ.

Minerals are *naturally* present at higher levels in *whole* grains than in *refined* grains. **Fortification** of refined flour with added iron (Table 6.2) is common. Zinc, calcium as well as vitamins may also be added at *levels beyond/not present in the original grain*.

Water is present in cereal grains at levels of 10–14 % of the grain. Of course soaking and cooking add water to cereal grains, and the grain size expands as additional water is absorbed. If a flour is *high* in protein content, it absorbs *a lot* of added water compared to *low* protein flour.

Fiber content is measured by *crude fiber* (CF) and *total dietary fiber* (TDF). These two measurements are *not* correlated. CF is composed of *cellulose* and the non-carbohydrate *lignin*. TDF includes cellulose and lignin, *plus hemicellulose, pectic substances, gums, and mucilages*.

Common Cereal Grains and Their Uses

Common cereal grains are noted below. While there is a great variety of cereal grains and their uses throughout the world, the most important and largest cereal grain consumed by man in the United States diet is *wheat*. That will be discussed first. Some wheat is also used for animal feed.

Wheat

Wheat has widespread uses. It may be cracked (bulgur, couscous), made into flour, and breads,

cereals, and pasta and is the basis of numerous products that are recognized in diets throughout the world (more later). Some individuals exhibit an intolerance or even an allergy to wheat and its protein (see Gluten Intolerance).

As noted, the wheat kernel (wheat berry) is the most common cereal milled into flour in the United States (see Fig. 6.2). There are over 30,000 varieties of wheat grown in the United States, grouped into the following *major* classifications: hard red winter, hard red spring, soft red winter, hard white wheat, soft white wheat, and durum wheat.

This large number of wheat varieties is named according to several factors—*season planted, texture, and color*.

- **Season**—wheat is classified as winter wheat or spring wheat. *Winter wheat* is planted in cold seasons such as Fall and Winter and is harvested in June or July. *Spring wheat* is the spring planting and is harvested in late summer or fall seasons.

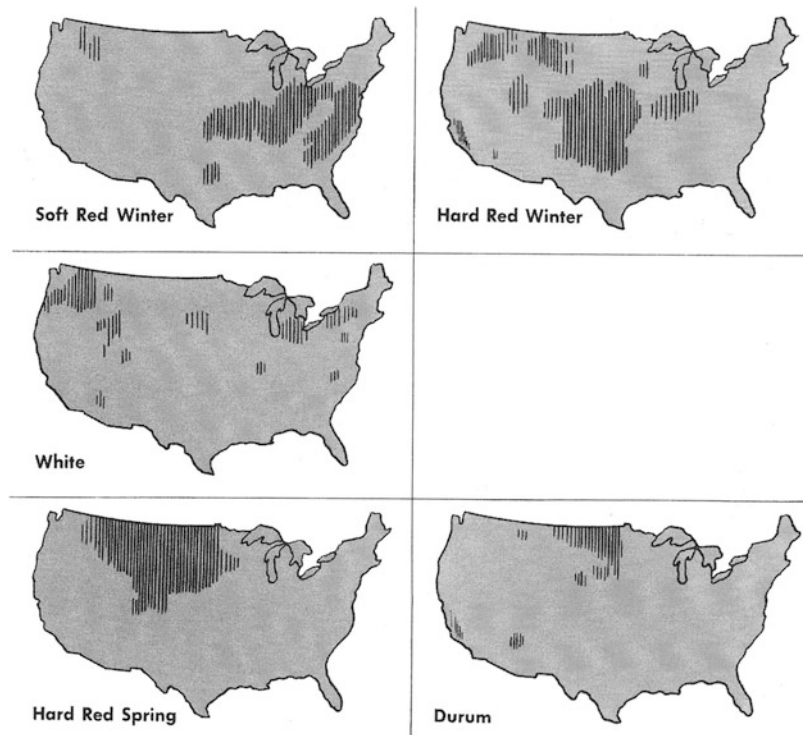
(Spring wheat may have a continuous growth cycle with no inactive period. In areas where winters are severe, such as northern North America, wheat is planted in the spring after there is no risk of frost. In areas with very mild winters, such as India or Australia, spring wheat is sown in the autumn and grows through the winter.)

- **Texture**—wheat is classified as either *hard* or *soft*. *Hard* wheat kernels contain strong protein–starch bonds, the kernel is tightly packed, and there are minimal air spaces. *Hard* wheat flour forms elastic dough due to its *high* gluten-forming protein content and is the best flour to use for bread making. *Hard spring* wheat is 12–18 % protein and *hard winter* wheat is 10–15 % protein.

Conversely, *soft* wheat is *lower* in protein and is desirable for cakes and pastries.

Starch–protein bonds in the kernel break down more easily in soft wheat, than hard. (Yet inherent differences in the starch or protein components of hard and soft wheat alone do *not* sufficiently explain the differences in hardness.) Hard and soft wheat may be blended to create all-purpose flour that contains about 10.5 % protein. In the absence

Fig. 6.2 Map showing wheat growth in the United States (Source: Wheat Flour Institute)



of pastry flour, “instant” (see below) flour and all-purpose flour may be combined.

- **Color**—*red*, *white*, and *amber*. The color of the grain depends on the presence of pigment, such as carotenoid. Durum wheat, for example, is hard wheat and highly pigmented. Its endosperm is milled into *semolina* for pasta, and couscous (most spaghetti is made from wheat).

Milling process of wheat. Specific milling tolerances of the ground wheat kernel or ‘berry’ must meet the Food and Drug Administration (FDA) grades to call the product “flour.” When milled, each 100 lb of wheat yields approximately 72 lb of white flour and 28 lb of other product, including animal feed.

The conventional milling process (Fig. 6.3) of wheat first involves washing to remove foreign substances such as dirt or rocks. Conditioning or tempering by adjustment to water level (the addition or removal of water) of the kernel follows in order to obtain the appropriate water content and to facilitate the easy separation of the kernel components. Next, wheat is subject to coarse

breaking of the kernels into *middlings*. The breaking process separates most of the kernels’ outside (bran) and inside core (germ) from the endosperm. Once the endosperm is separated, it is subsequently ground multiple times in reduction rolls to become finer and finer for flour. As the bran and germ are removed, the refined flour contains streams that contain less vitamins and minerals.

If flour streams of the endosperm are blended during the milling process, various flours are created. *Straight grade* flour is a combination of *all* of the mill streams. Typically, home and bakery operations use *patent flours* that are 85 % straight grade flour and the combination of various highly refined mill streams.

Patent flour is the highest grade of flour; hence, the highest in value. *Short-patent* flour, such as cake flour, contains *more starch* in the starch-protein matrix and is produced by combining fewer streams than the *higher-protein, long-patent* flour. The remainder of flour, not incorporated into patent flours, is *clear* flour. It is used when color is not of importance, as it is slightly gray.

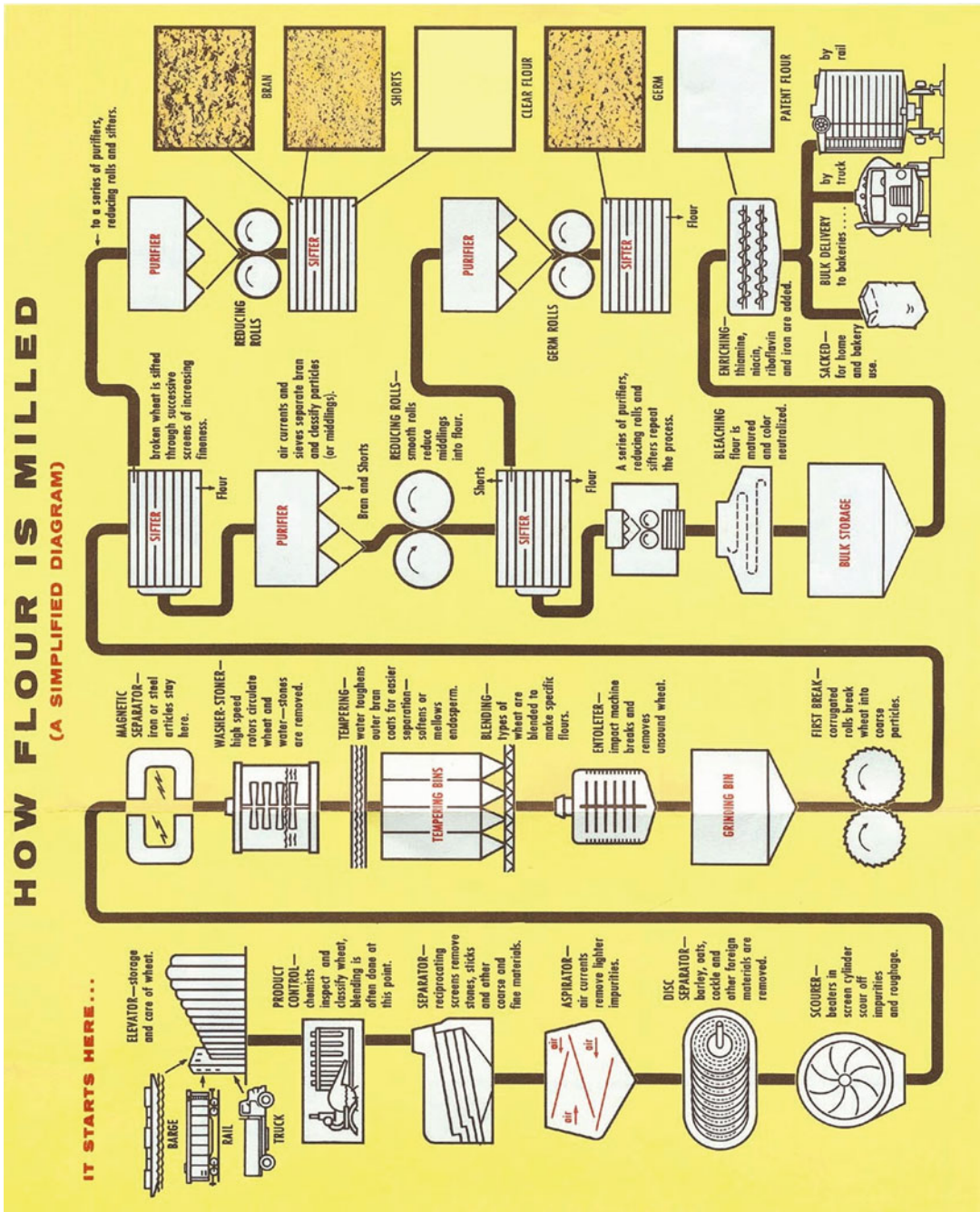


Fig. 6.3 The milling process (Source: Wheat Flour Institute)

It is the rule that flours from the *same* mill vary in composition from 1 year to the next. Also, the *various* flour production mills may produce slightly *different* flours, depending on such factors as geographic location of the crop, rainfall, soil, and temperature. It follows that this variance of crop year, mill, geographic location, and so forth may produce different baking results. For that reason, food manufacturers (and their Research and Development laboratory) constantly test flour so that variance is minimal or nonexistent. Otherwise flour may produce slightly different finished products. Of course, using *different flours* may produce *disastrous* results!

Additionally, milling produces the less common instant-blending, instantized, or “agglomerated” flour. Instant-blending flour is all-purpose flour that has been hydrated and dried, forming large “agglomerated” or clustered particles, larger than that the FDA approves for commercial white wheat flour. It has a more uniform particle size range than white wheat flour and does *not* readily pack down. Instant-blending flour is easily dispersible in water and is used when dispersibility of flour in liquid is preferred or required. It *mixes* into a formulation or recipe *better than* ordinary flour and is free-flowing, pouring like salt or sugar.

CULINARY ALERT! When a product formulation specifies a particular flour type, and that type is unavailable, the baker may combine various blends of flour to yield the correct flour product and better product results.

Milling (see Fig. 6.3) of various textures of wheat produces some of the following flours.

Hard Wheat: 10–18 % Protein

Bread flour

- It is typically made of hard red spring wheat kernels, with a high protein-to-starch ratio.

- It is capable of holding a lot of water (2 cups flour holds 1 cup water).
- It has a high gluten-forming potential forming a very strong and elastic structure, which can hold the air and gasses of yeast.
- It is not finely milled. Recall that hard spring wheat has a greater protein content than hard winter wheat. (“Gluten flour,” milled from spring wheat, may contain 40–45 % protein.)

Hard and Soft Wheat Blend: 10.5 % Protein

All-purpose flour

- Combines the desirable qualities of both hard and soft wheat flour.
- It does not contain bran or germ and is known as white wheat flour, or simply “flour.”
- It forms a less strong and elastic dough than bread flour.
- It may be enriched or bleached.

Soft Wheat: 7–9 % Protein

Cake flour

- Contains less protein, and more starch than all-purpose flour, and holds less water (2–3/4 cup holds 1 cup water)
- It is *low* in gluten-forming potential, is highly bleached, and finely milled (7/8 cup all-purpose flour + 2 tablespoons cornstarch = 1 cup cake flour).

Pastry flour

- It maintains intermediate characteristics of all-purpose and cake flour. It contains less starch than cake flour, and less protein than all-purpose flour.

Additional flour treatments involve the following:

- **Self-rising flour (phosphated flour)** contains 1–1/2 teaspoons of baking powder and 1/2 teaspoon of salt per cup of flour (and provides convenience!)
- **Bleached flour** is created when the yellowish (mainly xanthophyll) pigment is bleached by oxygen to a white color. Bleaching is achieved (1) naturally by exposure to oxygen in the air (2 or 3 months), or (2) by the chemical addition of either chlorine dioxide gas or benzoyl peroxide, *bleaching agents* which later evaporate. (Yes, even unbleached flour is bleached, naturally!) Bleaching results in finer grain and a higher volume.
- **Matured flour** also comes (1) naturally with age or (2) by the addition of *maturing agents*. If matured, gluten elasticity and baking properties of dough are improved because the unwanted effects of excess sulfhydryl groups are controlled. There is less polymerization of gluten protein molecules, and therefore, a less gummy dough (Chap. 20). Not all bleaching agents are maturing agents, yet chlorine dioxide (above) serves as both types of agent.
- **Organic (chemical-free) flour** uses grains that are grown without the application of synthetic herbicides and pesticides.

Wheat foods also include bulgur (Fig. 6.4), cracked wheat, and couscous as discussed below.

Bulgur is the whole kernel, i.e., parboiled, dried, and treated to remove a small percentage of the bran. It is then cracked and used as breakfast cereal or pilaf. Bulgur is similar in taste to wild rice.

Cracked wheat is similar to bulgur—the whole kernel broken into small pieces, yet not subject to parboiling. Whole grains should be stored in an airtight container, in a cool, dark



Fig. 6.4 Bulgur wheat (Source: Wheat Foods Council)



Fig. 6.5 Couscous (Source: Wheat Foods Council)

place. *Farina* is the pulverized wheat middlings of endosperm used predominantly as a cooked cereal. It is similar in appearance to grits (corn).

Couscous is a processed form of semolina wheat (Fig. 6.5). It is popular throughout the world, especially in Northern Africa and Latin America. It is often served as a pilaf or as tabouli.

In addition to wheat, other common grains are highlighted in the text that follows.

Rice

Rice is a major cereal grain whose varieties are used as *staple foods* by people throughout the

world. Thus, it may be the *major* aspect of a diet, or as well, incorporated to a *lesser degree* into the main dish, side dish, or dessert. It is commonly used in the preparation of r-t-e breakfast cereals. Rice, and rice flour, is especially important to persons with wheat allergies, or gluten intolerance, and rice is commonly eaten as a ‘first food’ by infants, as it is food that offers the least cereal allergy.

Rice may be eaten as the *whole grain*, or *polished*, which involves shedding the outer coat of bran. Brown rice contains the bran. Generally, rice is polished during milling in order to remove the brown hull; however, it *also* removes some of the protein, vitamins, and minerals. When left unpolished, whole rice is *more* subject to rancidity and favors deterioration, as well as insect infestation compared to polished, white rice.

Today, most white rice is enriched with vitamins and minerals, to add back nutrients lost in milling. (Recall, the once-prevalent deadly disease, beriberi resulted from eating polished rice as a staple food. Thiamin removed in the milling process.)

Enrichment (Table 6.3) of rice is common and may be achieved by two primary methods. *One method* is to coat the grain with a powder of thiamin and niacin, waterproof it, dry it, and then coat the grain with iron before it is dried again. *Another method* of enrichment involves parboiling or “converting” rice. This process allows water-soluble bran and germ nutrients to travel to the endosperm by boiling or a pressure steam treatment. As a result nutrients are retained when the outside hull is removed. Following the steaming process, rice is subsequently dried and polished. Optional enrichment may include vitamins such as riboflavin, and vitamin D, and the mineral calcium.

Rice is grown in a variety of sizes. *Long grain* rice (with three times the length as width) is *high in amylose* content. *Medium* and *short grain* rice contain *less* amylose. Rice remains *soft* in hot form; however, leftover rice is hard because the high amylose crystallizes, or hardens as it cools.

It is recommended that rice puddings prepared with leftover rice use *medium or short grain* varieties in the original cooking process since

Table 6.3 Primary nutrients for the enrichment of rice

Nutrient	mg/lb
Thiamin	2–4
Riboflavin	1.2–2.4
Niacin	16–32
Vitamin D	250–1,000
Iron	13–26
Calcium	500–1,000

they will contain less amylose and will not be texturally, as hard. The same medium or short grain rice is recommended for use in menu items such as sushi, where the food *should* remain soft and “stick” together.

Amylose content of rice	
Size variety	% Amylose
Short grain	15–20 % (less amylase, more sticky)
Medium grain	18–26 %
Long grain	23–26 % (high amylase, less sticky)

CULINARY ALERT! Short grain rice is *low* in amylose. It is sticky and holds ingredients together. Therefore, in a product such as sushi, short grain, sticky varieties of rice are preferable over long grain rice.

Rice may be modified to allow flavor and aroma variety, very detectable by some palates. “Rice” may even be made from *pasta* such as when macaroni is shaped to resemble rice in products such as RiceARoni[®]. It may be processed into flours, starches, cereals, cooking wine, or the Japanese wine, sake. Rice “milk” is commonly available and used. Rice flour is successfully made into items such as low-fat tortillas or noodles. Wild “rice” is actually *not* rice and, however, is derived from seeds of another reed-like water plant.

Numerous research studies have focused on shelf-stable cooked rice, ready-to-eat cereal, confectionery applications, rice oils, and flavored rice. Defatted rice bran extracts, aromatic rice, pregelatinized rice flours, starches, and rice syrups are chosen as food ingredients, depending upon the application. Rice use in a wide variety of foods continues to be common (Pszczola 2001).



Fig. 6.6 Corn taco shells (Courtesy of SYSCO® Incorporated)

Corn

Corn is a staple cereal food of many people and nations, although the majority of corn is used for animal feed. It is lacking in the two essential amino acids, tryptophan and lysine, yet research continues to explore the addition of a protein trait to corn DNA

Sweet corn is actually a cereal; however, it is commonly eaten as a vegetable. *Field corn* has non-vegetable uses, including starch that is of value to growers and consumers alike. The whole kernels of special breeds of corn containing 11–16 % moisture are desirable for popcorn where the kernel increases in volume as the water escapes as steam.

- The *whole or partial kernels* may be coarsely ground (perhaps stone-ground) and used to create cornmeal or masa. Cornmeal is popular in cornbread and tamales, corn tortillas, snack foods, and items such as taco shells (Fig. 6.6). It may be soaked in alkali, such as lime (calcium hydroxide) for 20–30 min, for a better amino



Fig. 6.7 Breads may be prepared using a variety of grains (Source: Wheat Foods Council)

acid balance and greater protein availability. This soaking process may sacrifice some niacin (vitamin B₃), however it adds calcium.

- The *endosperm* of corn may be made into hominy, ground into grits, or used in r-t-e breakfast cereals or cornstarch. It may be hydrolyzed in hydrochloric acid or treated with enzymes, to produce corn syrup, or high-fructose corn syrup (HFCS) (Chap. 14).
- The *germ* yields corn oil
- Corn and its finished products (corn syrup, etc.) may be allergens to some individuals

CULINARY ALERT! For use in bread making, corn needs to be combined with other flour, such as wheat flour, since corn alone yields dense bread. As well, corn does not contain the proteins gliadin and glutenin that form gluten structures.

Other Grains

Other grains, exclusive of the wheat, rice, and corn previously discussed, are *not* abundantly consumed, yet they offer taste variety (Fig. 6.7) and often grow in more adverse environmental conditions where the more common grains will not grow. For some readers, the following grains may be very familiar and frequently utilized. For

other readers, these same grains are *not* used at all or may be relatively unheard of! The seeds are used both as forage crops and as food cereals in different parts of the world.

Barley

Barley is “winter-hardy” and is able to survive in the frost of cold climates. It is used for human and animal consumption. Barley is served as a cooked cereal, or the hull of the kernel is removed by abrasion to create pearled barley, i.e., commonly used in soups. Additionally, although barley may not be eaten as a whole grain, it is incorporated into many foods including breads, pilafs or stuffing, or it may be used for *malt* production. Barley is the most common malt as it has sufficient enzyme content to hydrolyze the starch efficiently to sugar.

Malt

- In order to create malt, the barley grain is first soaked in water. This soaking causes the germ to sprout and produces an enzyme that hydrolyzes *starch* to a shorter carbon chain, maltose *sugar*. Maltose is a fermentable carbohydrate that is then used to feed yeast and produce CO₂ and ethyl alcohol. (The alcohol and CO₂ are important for brewing alcoholic beverages and for baking.) Dried malt is used in a variety of products including brewed beverages, baked products, breakfast cereal, candies, or malted milks.
- Consumers following a gluten-free diet (no wheat, oats, rye, or barley) must avoid malt. They should read ingredients labels to determine (1) *if* malt is an ingredient in the food, and (2) the *source* of the malt.

Millet

Millet is the general name for *small* seed grass crops. The crops are harvested for food or animal feed (fodder). It is a major crop in some countries

and is used as cereal, to make breads or soups. Millet includes proso (the most common) finger, foxtail, and pearl millet. Less common millets include barnyard, browntop, guinea, kodo, and little varieties of millet. Some millet is utilized in birdfeed, for cattle, hogs, poultry, and sheep.

Sorghum is a special type of millet with *large* seeds, typically used for animal feed, so far, yet it is the primary food grain in many parts of the world, where it is ground and made into porridge and cakes. It is also used to yield oil, sugars, and alcoholic beverages. A common variety of sorghum grown in the United States is milo; there are also waxy varieties. Overall, sorghums are resistant to heat and drought, and therefore, are of special value in arid, and hot regions of the world.

Sorghum is useful as a gluten-free way to produce malt. Sorghum and millet seeds are important cereals in semiarid, tropical regions of Asia and Africa.

A *very tiny* millet grain that has been used for centuries in the Ethiopian diet is *teff* or t’ef (*Eragrotis tef*, signifying “love” and “grass”). The seeds are approximately 1/32 of an inch in diameter, with 150 weighing as much as a kernel of wheat! Considering its size, it has a small endosperm in proportion to bran, and therefore is primarily bran, and germ. It is ground for use in flatbread. It grows in tropical climates in Africa, India, and South America. Commercial production of teff as a forage and food crop is also in the United States (Arrowhead Mills, Hereford, TX). It is cultivated in US states including Idaho and South Dakota.

Oats

Oat (referred to singularly when spoken of as a crop) is a significant cereal crop fed to animals such as horses and sheep, and also used by man. It is valued for its high protein content. In milling, the hull is removed and the oats are steamed and “rolled” or flattened for use in food. Oats are incorporated into many ready-to-eat breakfast

cereals and snack foods. Oat bran is a soluble fiber that has been shown to be effective in reducing serum cholesterol.

Due to the fact that oats have a fairly high fat content, as far as grains go, rancidity may develop. Lipase activity in the grain is destroyed by the administration of a few minutes of steam treatment.

Quinoa

Quinoa (keen-wa) is the grain highest in protein, although it is *not* an abundantly consumed grain. The small, round, light brown kernels are most often used as a cooked cereal.

Rye

Rye is richer than wheat in lysine, yet it has a relatively low gluten-forming potential.

Therefore, rye does not contribute as good of a structure to dough as is the case with wheat. It is frequently used in combination with wheat flour in breads and quick breads and is made into crackers. There are three types of rye—dark, medium, and light, which may be selected for baking into bread. Rye may be sprouted, producing malt or malt flour.

Triticale

Triticale is a *wheat* and *rye* hybrid, first produced in the United States in the late 1800s. As a crop, it offers the disease resistance of wheat and the hardiness of rye. It has more protein than either grain alone, although the overall crop yield is not high, so its use is not widespread. Triticale was developed to have the baking property of wheat (good gluten-forming potential) and the nutritional quality of rye (high lysine).

With regard to gluten intolerance or celiac disease, many grains are less subject to rigorous

testing than wheat, rye, barley, oats, and triticale. Considered to be “safe” on a gluten-restricted diet are grasses such as sorghum, millet, and teff.

Non-cereal “Flours”

Non-cereals, including various *legumes* and *vegetables*, may be processed into “flour,” although they do *not* have the composition of grains. For example, soy and garbanzo beans (chick peas) are legumes (from the Leguminosae family) that may be ground and added to baked products. These foods may be found on the list of common food allergens.

Soy “flour” may be incorporated into formulations due to its protein value, or because it aids in maintaining a soft crumb. Cottonseeds (Malvaceae family), and potatoes (tubers), may also be processed into “flour.” Buckwheat (fruit of *Fagopyrum esculentum* crop) contains approximately 60 % carbohydrate and may be used in the porridge kasha or as animal feed. Cassava (tuber) is the starch-yielding plant that yields tapioca and is a staple crop in parts of the world.

Cooking Cereals

In cooking, cereal products expand due to retention of the cooking water. *Finely* milled grains such as cornmeal, corn grits, or wheat farina should be *gently* boiled and only *occasionally* be stirred in order to prevent mushy and lumpy textures. *Whole or coarsely* milled grains such as barley, bulgur, rice, and oats (and buckwheat) may be added to *boiling* water and stirred occasionally during cooking.

To control heat while cooking, cereal products may be cooked in the top of a double boiler over boiling water. A disadvantage of this cooking method is that heating time is lengthened compared to direct heating without use of a double boiler.

More later, yet a bit regarding pasta: cooking pasta involves adding it to boiling water and

boiling it uncovered until the desired tenderness (typically al dente) is achieved. The addition of a small amount (1/2 teaspoon (2.5 mL) household use) of oil prevents boil-over from occurring.

CULINARY ALERT! Excessive stirring of any milled grain (especially finely milled grains) results in rupturing of the grain contents and is unpalatable, as the cereal forms a gummy, sticky consistency.



Fig. 6.8 Ready-to-eat breakfast cereal (Source: Wheat Foods Council)

Breakfast Cereals

Breakfast cereals may perhaps be eaten hot or cold. An American religious group not wanting to consume animal products started the production of ready-to-eat breakfast cereals. The *Western Health Reform Institute* in Battle Creek, Michigan, produced, baked, and then ground a whole meal product to benefit the healthfulness of its institute's patients. A local townspeople, J. H. Kellogg, and his brother W.K. Kellogg started a business with this idea, applying it to breakfast food. A patient, C.W. Post did the same. (Both the Kellogg and Post names are still popular cereal manufacturers today.)

Breakfast cereals (Fig. 6.8) in many forms quickly became popular. Flaking, shredding, puffing, etc. and the production of various forms soon expanded although convenient, some criticize the levels of ingredients, including sugar and fiber, in r-t-e breakfast cereals. *Enrichment* and *fortification* also became a common practice for breakfast cereals that are now in the ranking of one of the most fortified foods available for consumption.

Pasta

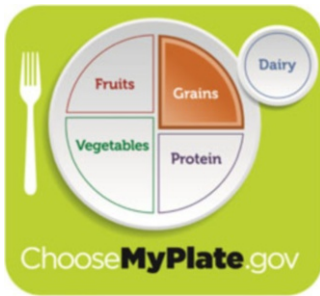
Pasta is the paste of milled grains (alimentary paste), extruded through a die or put through a roller. The crushed (not finely ground) endosperm of milled durum spring wheat, known as *semolina*, is used in the preparation of high-quality pasta products. *Lower-quality* pastas that do not use semolina are also available to the consumer. These typically taste "starchy" and are pasty in texture. Although taste may not be affected, rinsing cooked pasta products prior to service may result in the loss of nutrient enrichment.

Pasta frequently appears on restaurant menus and home tables in the form of salads, side dishes, and main dishes. If pasta is processed to include legumes, as part of the formulation, a *complete protein* may be formed in a single food. For instance, pasta may now be commercially formulated to include pureed vegetables, herbs, and spices as well as cheeses. Pasta may also be cholesterol-free or gluten-free, made of non-wheat

flour, such as rice. “Technological breakthroughs now make it possible to enjoy rice pasta that tastes, looks, and cooks like regular pasta.”

A variety of products including macaroni, noodles, and spaghetti are created by extrusion. In order to distinguish between macaroni and noodles, *macaroni* does not include eggs in its formulation and *noodles* must contain not less than 5.5 % (by weight) of egg solids or yolk (National Pasta Association, Arlington, VA).

Nutritive Value of Grains



Grains Group	Vegetable Group	Fruit Group	Dairy Group	Protein Foods Group
Make at least half your grains whole.	Vary your veggies.	Focus on fruits.	Get your calcium-rich foods.	Go lean with protein.

What Foods Are in the Grains Group?

Any food made from wheat, rice, oats, cornmeal, barley, or another cereal grain is a grain product. Bread, pasta, oatmeal, breakfast cereals, tortillas, and grits are examples of grain products.

Grains are divided into two subgroups, Whole Grains and Refined Grains.

Whole grains contain the entire grain kernel—the bran, germ, and endosperm.



Refined grains have been milled, a process that removes the bran and germ. This is done to give grains a finer texture and improve their shelf-life, but it also removes dietary fiber, iron, and many B vitamins.



Most refined grains are *enriched*. This means certain B vitamins (thiamin, riboflavin, niacin, folic acid) and iron are added back after processing. Fiber is not added back to enriched grains. Check the ingredient list on refined grain products to make sure that the word “enriched” is included in the grain name. Some food products are made from mixtures of whole grains and refined grains.

Most of these products are made from refined grains. Some are made from whole grains. Check the ingredient list for the words “whole grain” or “whole wheat” to decide if they are made from a whole grain. Some foods are made from a mixture of whole and refined grains.

Some grain products contain significant amounts of bran. Bran provides fiber, which is important for health.

10 tips

Nutrition
Education Series

make half your grains whole



10 tips to help you eat whole grains

Any food made from wheat, rice, oats, cornmeal, barley, or another cereal grain is a grain product. Bread, pasta, oatmeal, breakfast cereals, tortillas, and grits are examples. Grains are divided into two subgroups, **whole grains** and **refined grains**. Whole grains contain the entire grain kernel—the bran, germ, and endosperm. People who eat whole grains as part of a healthy diet have a reduced risk of some chronic diseases.

1 make simple switches

To make half your grains whole grains, substitute a whole-grain product for a refined-grain product. For example, eat 100% whole-wheat bread or bagels instead of white bread or bagels, or brown rice instead of white rice.



2 whole grains can be healthy snacks



Popcorn, a whole grain, can be a healthy snack. Make it with little or no added salt or butter.

Also, try 100% whole-wheat or rye crackers.

3 save some time

Cook extra bulgur or barley when you have time. Freeze half to heat and serve later as a quick side dish.

4 mix it up with whole grains

Use whole grains in mixed dishes, such as barley in vegetable soups or stews and bulgur wheat in casseroles or stir-fries. Try a quinoa salad or pilaf.

5 try whole-wheat versions

For a change, try brown rice or whole-wheat pasta. Try brown rice stuffing in baked green peppers or tomatoes, and whole-wheat macaroni in macaroni and cheese.



6 bake up some whole-grain goodness

Experiment by substituting buckwheat, millet, or oat flour for up to half of the flour in pancake, waffle, muffin, or other flour-based recipes. They may need a bit more leavening in order to rise.

7 be a good role model for children

Set a good example for children by serving and eating whole grains every day with meals or as snacks.

8 check the label for fiber

Use the Nutrition Facts label to check the fiber content of whole-grain foods. Good sources of fiber contain 10% to 19% of the Daily Value; excellent sources contain 20% or more.



9 know what to look for on the ingredients list

Read the ingredients list and choose products that name a whole-grain ingredient **first** on the list. Look for “whole wheat,” “brown rice,” “bulgur,” “buckwheat,” “oatmeal,” “whole-grain cornmeal,” “whole oats,” “whole rye,” or “wild rice.”

10 be a smart shopper

The color of a food is not an indication that it is a whole-grain food. Foods labeled as “multi-grain,” “stone-ground,” “100% wheat,” “cracked wheat,” “seven-grain,” or “bran” are usually not 100% whole-grain products, and may not contain **any** whole grain.



10 tips
Nutrition
Education Series

choosing whole-grain foods



10 tips for purchasing and storing whole-grain foods

Whole grains are important sources of nutrients like zinc, magnesium, B vitamins, and fiber.

There are many choices available to make half your grains whole grains. But whole-grain foods should be handled with care. Over time and if not properly stored, oils in whole grains can cause spoilage. Consider these tips to select whole-grain products and keep them fresh and safe to eat.

1 search the label

Whole grains can be an easy choice when preparing meals. Choose whole-grain breads, breakfast cereals, and other prepared foods. Look at the Nutrition Facts labels to find choices lower in sodium, saturated (solid) fat, and sugars.



2 look for the word “whole” at the beginning of the ingredients list

Some whole-grain ingredients include whole oats, whole-wheat flour, whole-grain corn, whole-grain brown rice, wild rice, and whole rye. Foods that say “multi-grain,” “100% wheat,” “high fiber,” or are brown in color may not be a whole-grain product.

3 kids can choose whole grains

The new school meal standards make it easier for your kids to choose whole grains at school. You can help your child adapt to the changes by slowly adding whole grains into their favorite recipes, meals, and snacks at home.

4 find the fiber on label

If the product provides at least 3 grams of fiber per serving, it is a good source of fiber. If it contains 5 or more grams of fiber per serving, it is an excellent source of fiber.

5 is gluten in whole grains?

People who can't eat wheat gluten can eat whole grains if they choose carefully. There are many whole-grain products, such as buckwheat, certified gluten-free oats or oatmeal, popcorn, brown rice, wild rice, and quinoa that fit gluten-free diet needs.



6 check for freshness

Buy whole-grain products that are tightly packaged and well sealed. Grains should always look and smell fresh. Also, check the expiration date and storage guidelines on the package.

7 keep a lid on it

When storing whole grains from bulk bins, use containers with tight-fitting lids and keep in a cool, dry location. A sealed container is important for maintaining freshness and reducing the possibility of bug infestations or moisture.

8 buy what you need

Purchase smaller quantities of whole-grain products to reduce spoilage. Most grains in sealed packaging can be kept in the freezer.



9 wrap it up

Whole-grain bread is best stored at room temperature in its original packaging, tightly closed with a quick-lock or twist tie. The refrigerator will cause bread to lose moisture quickly and become stale. Properly wrapped bread will store well in the freezer.

10 what's the shelf life?

Since the oil in various whole-grain flours differs, the shelf life varies too. Most whole-grain flours keep well in the refrigerator for 2 to 3 months and in the freezer for 6 to 8 months. Cooked brown rice can be refrigerated 3 to 5 days and can be frozen up to 6 months.

Key Consumer Message: Make at least half of your grains whole grains.

[View Grains Food Gallery](#)

Grains make a significant nutritive contribution to the diet (Sebrell 1992). Whole grain products and processed cereal products contribute carbohydrates, vitamins such as B vitamins, minerals such as iron, and fiber to the diet in creative ways. Fortification with vitamin D and calcium are presently under consideration. Ready-to-eat varieties of breakfast cereals are frequently consumed in the more developed countries and many are highly fortified with essential vitamins and minerals, including folate.

Grains are low in fat, high in fiber, and contain no cholesterol, *although* cooked foods, breads, cereals, rice, and pasta dishes may be prepared with added fats, sugars, eggs, and refined flours, which changes the nutritive value profile. Unfortunately, with these additions, many commonly selected r-t-e breakfast cereals lose their original nutritional benefit, as they are manufactured to be high in sugar and/or low in fiber in developed countries.

Safety of Grains

Safety of cereal grains is better assured by proper storage including first-in-first-out (FIFO) rotation. Since whole grains are subjective to rancidity, storage should be kept cold, and not lengthy. All products should be stored off of the floor and a slight distance away from walls due to possible pipe flooding or insect infestation.

Conclusion

Cereals are the edible seeds of cultivated grasses and many cereal foods are prepared from grain. A kernel contains bran, endosperm, and germ, however, if “refined,” the refined cereals contain *only* endosperm and are no longer whole grain. For example, *wheat flour* is not the same as *whole*

wheat flour. Common cereal grains include wheat, rice, and corn, although other grains such as barley, millet, oats, quinoa, rye, and triticale may be used as a component in meals. Dried grains have a very long storage life, and much of the world depends on them for food.

Over 30,000 varieties of wheat exist, classified according to season, texture, and color. *Hard* wheat is used for bread making, and *soft* wheat for cakes and pastries.

Semolina flour from hard durum wheat is used for pasta production. Pasta is the paste of milled grains, primarily wheat, and increasingly appears in the American diet. It is a complex carbohydrate and low-fat food.

Rice is a staple food of much of the world. It grows as (extra long), long, medium, and short grain rice and grows in a variety of flavors that are used in many entrees, side dishes, even desserts. Corn is also common.

Cereals are included as the base of numerous food guides throughout the world, indicating that they are major foods of a nutritious diet. The USDA recommends that persons avail themselves of the great variety of products that are available in the marketplace.

Notes

CULINARY ALERT!

Glossary

All-purpose wheat flour White flour, not containing the bran or germ. Combining the properties of hard and soft wheat.

Bleached flour Bleaching the pigment to a whiter color, naturally by exposing pigment to air, or by chemical agents.

Bran The layered outer coating of the kernel, offering protection for the seed.

Bread flour Made from a hard wheat kernel, with a high protein–starch ratio; high gluten potential.

Cereal Any edible grain that comes from cultivated grasses.

Endosperm The starch-storing portion of the seed that produces white flour and gluten.

Enrichment Adding back nutrients lost in milling.

Fortification Adding nutrients at levels beyond that present in the original grain.

Germ The embryo; the inner portion of the kernel.

Gluten Protein substances (gliadins, glutenins) left in the flour after the starch have been removed, which when hydrated and manipulated produce the elastic, cohesive structure of dough.

Malt Produced from a sprouting barley germ. Long glucose chains are hydrolyzed by an enzyme to maltose, i.e., involved in both feeding yeast and producing CO₂. May be dried and added to numerous products.

Matured flour Wheat flour, i.e., aged naturally or by chemical agents to improve gluten elasticity and baking properties of dough.

Organic flour Flour from crops grown without the use of chemicals such as herbicides and insecticides.

Patent flour Highest grade of flour from mill streams at the beginning of the reduction rolls. High starch, less protein than mill streams at the end of reduction rolls.

Pasta The paste of milled grains, usually the semolina from durum wheat, extruded through a die to produce a diversity of shaped products. They are dried and then cooked in

large amounts of water. Included are macaroni, noodles, spaghetti, ravioli, and the like.

Semolina Flour milled from durum wheat.

Other/Additional Glossary for Cereals, Flour, and Flour Mixtures

Oregon State University Select definitions for a better understanding of cereals, flour, and flour mixtures.

Amylopectin A fraction of starch with a highly branched and bushy type of molecular structure.

Amylose The long-chain or linear fraction of starch.

Baking powder Is a mixture consisting generally of an acid salt and sodium bicarbonate which, when water is added, and possibly heat, will produce carbon dioxide for leavening.

Batter Systems with their relative high water: flour: water is continuous. Structure depends much less on gluten development than on gelatinization of starch.

Bleaching Of flour is the oxidization of the yellow carotenoid pigments in wheat flour. This may be done with either chemicals or during “aging” over a length of time.

Carmelization The development of brown color and caramel flavor as dry sugar is heated to a high temperature; chemical decomposition occurs in the sugar.

Carotenoid pigment Yellow-orange compounds produced by plant cells and found in various fruit, vegetable, and cereal grain tissues; for example, beta-carotene.

Coagulation Change in protein, after it has been denatured, that results in hardening or precipitation and is often accomplished by heating.

Fermentation The transformation of organic substances into smaller molecules by the action of microorganisms; yeast ferments glucose to yield carbon dioxide and alcohol.

Gliadin Is the water-insoluble protein that contributes stickiness and tackiness to gluten structure.

Gluten Is an elastic cohesive mass made up of gliadin, glutenin, water, and a lipoprotein compound.

Glutenin Is the water-insoluble protein that contributes toughness and rubberiness to gluten structure.

Graham flour Is flour essentially from the entire wheat kernel. It may be ground to varying degrees.

Green flour Is flour which has not been aged or matured.

Maturing Of flour is the aging process that affects the flour structural proteins through oxidation of the gliadin and glutenin. Maturing may occur naturally or with chemical additions.

Milling Is the process which generally involves the separation of the bran and germ from the endosperm which is subsequently subdivided.

Oxidation A chemical reaction in which oxygen is added or electrons are lost.

Proofing The last rising of bread dough after it is molded into a loaf and placed in the baking pan.

Reducing substance A molecule that has an effect opposite that of an oxidizing agent: hydrogen or electrons are gained in a reaction involving reducing substances.

Rope Is a bacterial contamination that can originate in the flour bin or in the various constituents used to make bread. It will make a loaf of bread sticky and “ropy” in the interior.

Staling Refers to those changes in quality that occur in baked products after baking. Generally, there is a loss of flavor, softening of the crust or development of a leathery crust, and increased firmness of the crumb.

Starch gelatinization The swelling of starch granules when heated with water, often resulting in thickening.

Straight grade white flour Theoretically should contain all the flour streams resulting from the milling process, but actually 2–3 % of the poorest streams are withheld.

White wheat Flour is a food made by the grinding and sifting of cleaned wheat (definition, FDA).

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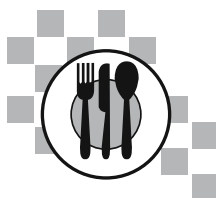
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Introduction

Vegetables are the edible portion of plants eaten with (or as) the main course. They are in salads and soups. Vegetables may be processed into beverages or vegetable starches, eaten fresh or lightly processed, dried, pickled, or frozen. They impart their own characteristic flavor, color, and texture to diets, and undergo changes during storage and cooking. Ranked next to the cereal crops wheat, rice, and corn, potatoes are the most prolific vegetable crop grown for human consumption.

Fruits are defined in more than one way. *Botanically*, fruits are the mature ovaries of plants with their seeds. Therefore this definition includes all grains, legumes, nuts and seeds, and common “vegetable-fruits” such as cucumbers, olives, peppers, and tomatoes. When defined and considered in a *culinary role*, fruit is the fleshy part of a plant, usually eaten alone or served as a dessert. Fruits are high in organic acids and sugar—higher than vegetables.

The nutritive value of vitamins, minerals, fiber, and other compounds contained in fruits and vegetables is extremely important to the diet. Additional dietary and medicinal benefits of fruits and vegetables are being discovered. “Vary your veggies” and “focus on fruits” is the USDA advice in selecting vegetables and fruits

as part of a healthy diet. Also given as USDA advice is “make half your plate fruits and vegetables.”

Structure and Composition of Cell Tissue

The structure and composition of vegetables and fruits show that they contain both *simple* and *complex* cells. The *simple* cells are similar to one another in function and structure and include *dermal* tissue and *parenchyma* tissue. Dermal tissue is the single-layer *outside* surface of leaves, young stems, roots, and flowers, while ***parenchyma tissue*** (*see below*) makes up the majority of the plant, and is where basic molecular activity such as the synthesis and storage of carbohydrate by sunlight (photosynthesis) occurs.

Complex tissue includes the vascular, collenchyma, and sclerenchyma supporting tissue. Major vascular tissue consists of the xylem and phloem; *xylem* conducts water from the roots to the leaves, and *phloem* conducts nutrients from the leaves to the roots. These tissues may be located in the center of the vegetable, for example, as is seen in carrots.

A plant is composed *primarily* of simple *parenchyma* tissue (Fig. 7.1). Each cell is bounded by a cell wall produced internally by

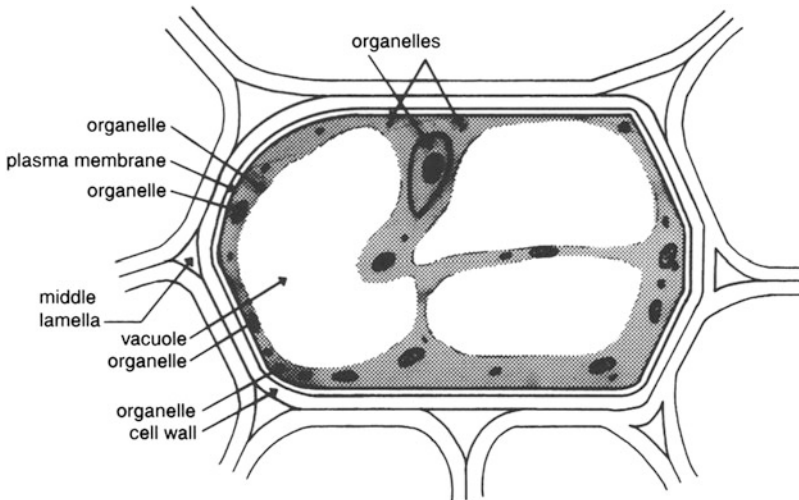


Fig. 7.1 Components of a parenchyma cell (Source: Division of Nutritional Sciences, New York State College of Human Ecology)

the protoplast. The wall serves to support and protect cell contents and their retention, influx, or release. When the wall is *firm*, the original shape and texture of the cell are maintained. However, when the wall is *destroyed* (by cutting, dehydration, or cooking), it breaks and spills its contents into the surrounding environment. Thus, water, sugars, or water-soluble vitamins of a cell may be lost.

The *primary* cell wall is made of **cellulose**, hemicellulose, and pectic substances including pectin. Older, more mature plants may also have a *secondary* cell wall composed of **lignin** (see “Chemical Composition of Plant Material” section), in addition to the primary cell wall.

Inside the parenchyma cell wall is the protoplast, composed of three parts—*plasma membrane*, *cytoplasm*, and *organelles*. The *plasma membrane* surrounds the functional cell, while the *cytoplasm* of the protoplast includes all of the cell contents inside the membrane, yet outside the nucleus. The *organelles* include nucleus, mitochondria, ribosomes, and plastids. It is the plastids that contain fat-soluble material such as fat-soluble vitamins, and fat-soluble pigments including chlorophyll and carotenoids (each is discussed in a subsequent section of this chapter.)

Outside the cell wall, *between* adjacent cells, is the **middle lamella**. This is the “cementing” material between adjacent cells and it contains pectic substances, magnesium and calcium, water, and air spaces.

Each parenchyma cell contains an inside cavity known as a **vacuole**. It may be *large* in size, holding plentiful amounts of water, and comprising the major portion of parenchyma cells, or it may be *small* in size. In an intact, *uncooked* cell, vacuoles hold sufficient water and provide a desirable *crisp* texture to the cell. The opposite effect is noted in *wilted* or cooked cells.

The **cell sap** of the vacuole contains the water-soluble materials including vitamins B and C, sugars, inorganic salts, organic acids, sulfur compounds, and the water-soluble pigments. These cell sap components may escape into the surrounding soaking/rehydrating/cooking water.

Chemical Composition of Plant Material

Carbohydrate

Carbohydrate constitutes the *largest* percentage of the dry weight of plant material. It is the basic

molecule formed during *photosynthesis* when water (H₂O) and carbon dioxide (CO₂) combine to yield carbohydrate (CHO) and oxygen (O₂).

Carbohydrate is present in both the simple and complex forms. For example, *simple* carbohydrates are the *monosaccharides*—including *glucose* and *fructose*; and *disaccharides*, such as *sucrose*, that may increase during the fruit ripening process. *Complex* carbohydrates or *polysaccharides* are synthesized from simple carbohydrates and include *cellulose* and *starch*.

Various complex carbohydrates and the effect of heat on those carbohydrates are discussed in the following (see also Chap. 3)

Starch is the storage component of carbohydrate located in roots, tubers, stems, and seeds of plants. When subjected to heat and water, starch absorbs water and gelatinizes (Chap. 4). Vegetables vary in their starch content. Some vegetables such as potatoes are starchy, some moderate, and others such as parsley are less starchy. Starch is digestible as the bonds between the glucose units are α -1,4.

Cellulose is water-insoluble fiber that provides *structure* to plant cell walls. The molecular bonds between glucose units are β -1,4; therefore, cellulose remains *indigestible* to humans, although it may be softened in cooking.

Hemicellulose fiber provides structure in cell walls, and the majority is *insoluble*. It is softened when heated in an alkaline environment, such as, if baking soda is added to cooking water for the purpose of green color retention.

Pectic substances (Chap. 5) are the firm, intercellular “cement” between cell walls, the gel-forming polysaccharide of plant tissue, and are hydrolyzed by cooking. Large *insoluble* forms of pectin become *soluble* pectin with ripening of the plant material.

In addition to carbohydrates, there is a noncarbohydrate fiber material present in the complex vascular and supporting tissue. It is **lignin** and is found in older vegetables. Lignin remains unchanged by heat and may exhibit an unacceptable “woody” texture.

Protein

Protein makes up less than 1 % of the composition of a *fruit*, and protein is *low* in most *vegetables*. Protein is most prevalent in legumes—peas and beans—yet, even then, it is an *incomplete* protein as it lacks the essential amino acid, methionine.

Protein that is present as enzymes may be extracted from plants and used in other foods. Examples include the proteolytic enzymes that contribute the beneficial tenderizing effects to meats such as *papain* (derived from papaya), *ficin* (obtained from figs), and *bromelain* (extracted from pineapple).

Fat

Fat composes approximately 5 % of the dry weight of roots, stems, and leaves of vegetables. It makes up less than 1 % of the dry weight of a fruit, except for fruits such as avocados and olives that contain 16 % and 14 % fat, respectively. Fat is instrumental in development during the early growth of a plant.

Vitamins

The vitamins present in vegetables and fruit are primarily *carotene* (a vitamin A precursor) and *vitamin C*. *Beta-carotene*, is present in dark orange fruits, vegetables, and as an underlying pigment in green vegetables. Vitamin B₁ (thiamin) is also present. Fruits supply more than 90 % of the water-soluble vitamin C and a major percentage of the fat soluble vitamin A in a diet.

Water-soluble vitamin losses may occur upon soaking when vitamins leach out, and also in heating. Losses occur primarily in heating. In addition to soaking and heating, enzymatic action may negatively affect the nutritive quality of fruits and vegetables. Specifically, the enzymes, ascorbic acid oxidase and thiaminase, can cause nutritional changes in vitamins C and B₁, respectively, during storage. Therefore, retention of these vitamins is controlled by deactivating the enzymes in blanching prior to freezing.

CULINARY ALERT! It is interesting to note that vitamins A and C, so plentiful in fruits and vegetables, are both listed on Nutrient Facts labels as vitamins that Americans lack, therefore increase consumption of fruits and vegetables.

Minerals

Minerals are more prolific in vegetables than in fruits and are notably calcium, magnesium, and iron. Calcium ions are *added* to some canned vegetables in order to promote firmness and lessen softening of pectic substances. Yet, since the oxalic acid in spinach and the phytates in peas *bind calcium*, decreasing its bioavailability, calcium is *not* added to these canned vegetables.

Water

Water is found *in* and *between* plant cell walls. Some of its functions in the plant are to transport nutrients, to promote chemical reactions, and to provide plants with a crisp texture if cell membranes are intact.

Water constitutes a small percentage (10 %) of seeds and is a substantially larger percent of leaves. It makes up 80–90 % of a plant, as is evidenced by the drastic size reduction of a measure of vegetables that is subject to dehydration.

CULINARY ALERT! Think about how the volume of plant material changes significantly

when a food dehydrator is used to remove water from food.

Phytochemicals (More in Appendices)

Phytochemicals are plant chemicals. They are non-nutrient materials that may be especially significant in preventing disease and controlling cancer. These chemicals are the focus of much research concerning their importance to human health.

The list is long of the many examples of such plant chemicals. It includes the beta-carotene of carotenoid pigments, the flavonoid group of pigments, as well as the sulfur-containing allyl sulfide and sulforaphane. Additionally, dithiols, indoles, and isothiocyanates in cruciferous (“cross-shaped blossom,” cabbage family) vegetables, isoflavones, phytosterols, protease inhibitors, saponins in legumes, and limonene and the phenols of citrus fruit are among the plant chemicals that may be effective in disease prevention.

Turgor Pressure

A plant’s **turgor pressure** is the pressure that water-filled vacuoles exert on the cytoplasm and the partially elastic cell wall. A raw product still attached to the plant prior to harvesting is generally crisp because the vegetable or fruit contains a large percentage of water, which provides turgidity to the plant. As previously mentioned, the structure of plant material is, to a large degree, dependent on the water content of the parenchyma cell.

Shortly after the fruit or vegetable is “picked” from the plant, water is lost to the air (evaporation) due to air flow with its evaporation, or due to low humidity storage. As a result, there is a loss of turgor pressure. The product becomes limp, wilted, and dehydrated. If the parenchyma cell is still *intact* (*not cooked* or otherwise destroyed), water may reenter the cell, and turgor

of this wilted, limp product may be restored. Soaking is an example of rehydration.

CULINARY ALERT! It is possible to rehydrate or recrisp by storage in high humidity (refrigerator's hydrator box or crisper) or by minimal soaking in warm, 70–90 °F (21–32 °C), water.

Subsequent to soaking, when plant pores open and take up water, the plant pores then re-close, and hold the absorbed water for approximately 6 h if the plant is refrigerated (Produce Marketing Association, Newark, DE). Soaking raw plant material may be discouraged though, as water-soluble nutrients and pigments may, by purely physical means, escape into the soaked water. [To rehydrate lettuce, it is suggested that it should not be soaked, except rather, placed in only 2 in. or so of warm water (Produce Marketing Association, Newark, DE).] Sprays of dips to make the produce waterproof may also be employed.

Once the parenchyma cell is subjected to cooking, *osmosis* ceases and *diffusion* occurs, which changes the texture, flavor, and shape of fruits. *Osmosis* represents water movement across a semipermeable membrane. *Diffusion* signifies water *and solute* movement across a *permeable* membrane.

Pigments and Effects of Additional Substances

Plant pigments enhance the aesthetic value of fruits and vegetables for humans, as well as attract insects and birds, which fosters pollination. These pigments are subject to change with ripening and processing of the raw vegetables or fruits. The four pigments found in plants are *chlorophyll*, the green pigment; *carotenoids*, a yellow, red, or orange pigment; and the flavonoids, both *anthocyanin*, the red, blue, or purple pigment, and *anthoxanthin*, the white pigment. "... a variety of different colors of non-starchy vegetables and fruits, including red, green, yellow, white, purple and orange, as well

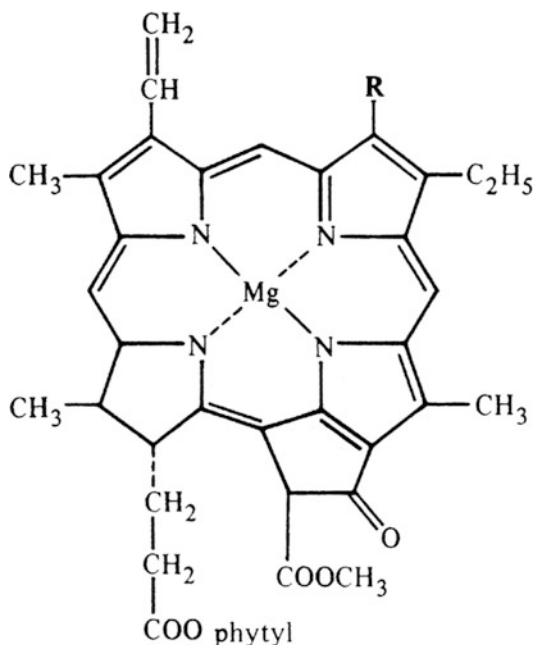


Fig. 7.2 Chlorophyll

as tomato-based products and allium vegetables, such as garlic, are recommended daily.” (Food Product Design 2012)

High-performance liquid chromatography (HPLC) is generally used for plant pigment analysis. A discussion of the major pigments and a description of how they may change appears in the following material.

Chlorophyll

Chlorophyll is perhaps the most well-recognized plant pigment. It is the green pigment found in the cell chloroplast, and it is responsible for photosynthesis (i.e., converting sunlight to chemical energy). It is *fat-soluble* and may appear in vegetable cooking water if the water also contains fat.

Chlorophyll is structurally a porphyrin ring containing magnesium at the center of a ring of four pyrrole groups (Fig. 7.2). Phytol alcohol is esterified to one of the pyrrole groups, and it confers solubility to fat and fat solvents. Methyl alcohol is attached to another pyrrole group.

If the magnesium in chlorophyll is *displaced* from its central position on the porphyrin ring, an *irreversible* pigment change occurs. A number of factors cause this pigment color change, including prolonged storage, the heat of *cooking*, changes in *hydrogen ion* concentration (pH), and the presence of the minerals, zinc and copper. These factors are responsible for producing a drab, olive-green colored pigment in the *cooked* product. In a *raw* form the cell membrane does not allow H to contact/change a pigment.

Initially, as green vegetables are *heated*, air is removed from *in* and *between* the cell, and a *bright green* color becomes apparent. Then internal organic acids are released and hydrogen displaces magnesium, producing pheophytins. Either magnesium-free *pheophytin a*, which is a gray-green pigment, or *pheophytin b*, an olive-green pigment, is formed. These changes to the chlorophyll pigment become more marked with time, so a short cooking time is recommended.

As well, cooking the product *uncovered* for the first 3 minutes allows the escape of volatile plant acids that would otherwise remain in the cooking water and react to displace magnesium. Using a cover while cooking allows less change of chlorophyll to occur. (This is not true of all vegetable pigments as seen later.)

When *heated*, green-pigmented vegetables that are *high* in acid content undergo *more* color change than green vegetables *low* in acid, and green vegetables show less color change than fruits with their *high* acid. Even *raw* green vegetables, such as *raw* broccoli, change color to the underlying yellowish color as the chlorophyll degrades.

CULINARY ALERT! Pigments may change from the natural color due to extended heating and release of the plant's *internal* organic acids; therefore, minimum cooking is preferred. In addition to the internal organic acids, an *external* acid environment (i.e., acid added to cooking water) causes the natural green color to change into olive-green pheophytin.

The preceding discussion has been on the effect of *acids* on pigment color. As opposed to an acid environment, an *alkaline* environment

also affects the green pigment. As the professional or home chef knows, the addition of the alkaline material, sodium bicarbonate (baking soda), produces and maintains a desirable green color. The soda reacts with chlorophyll, displacing the phytyl and methyl groups on the molecule, and the green pigment forms a bright-green, water-soluble chlorophyllin.

Nonetheless, although producing a desirable *appearance* with pH change of added soda, the benefit is accompanied by an unacceptable 1. *loss of texture*, due to softening of hemicellulose. Sodium bicarbonate also 2. *destroys ascorbic acid* (vitamin C) and *thiamin* (vitamin B₁). Therefore, due to these texture and nutrient losses the addition of this alkali substance is *not* recommended.

CULINARY ALERT! Sodium bicarbonate (baking soda) has a positive effect on color. However, it negatively affects texture and nutritive value.

In food preparation, the minerals, copper and zinc, may be released in the process of cutting or chopping. Also, some knives, copper bowls, or colanders may produce *undesirable* color changes in chlorophyll by displacing magnesium.

Regardless of the manner in which chlorophyll is changed, when the chlorophyll is destroyed, a second underlying carotenoid pigment may become apparent. Carotenoids are discussed below.

Carotenoids

The *carotenoids* are red, orange, and yellow *fat-soluble* pigments in fruits and vegetables, including *carotenes* (the hydrocarbon classification) and *xanthophylls* (the oxygenated class). They are found in chloroplasts along with chlorophyll, where the green pigment dominates, and also in chromoplasts without chlorophyll. The carotenoid pigment is seen especially in flowers, fruits, including tomatoes, peppers, and citrus fruits, as

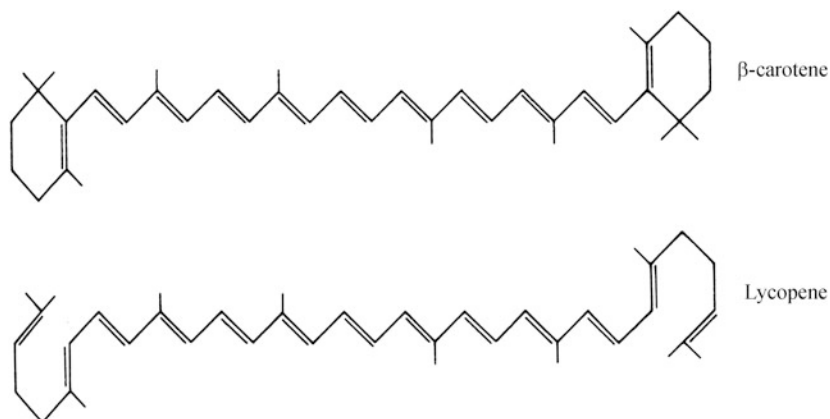


Fig. 7.3 Beta-carotene, lycopene

well as roots, including carrots and sweet potatoes.

Carotenes are unsaturated hydrocarbons containing many carbon atoms. The conjugated double bonds (i.e., double bonds alternating with single bonds) are responsible for the color; the greater the number of conjugated double bonds, the deeper the color. For example,

- *Beta-carotene* is naturally orange in color and contains a six-membered ring at each end of the chain (Fig. 7.3) In comparison to beta-carotene:
 - *Alpha-carotene* has one *less* conjugated double bond and is *paler* in color.
 - *Lycopene*, found in tomatoes and watermelon, has the *deepest red-orange color* because it has two *more* double bonds than beta-carotene, and it has two open rings (Fig. 7.3) at each end of the chain.

There exist hundreds of types of carotenes—40 or more carotenoids are known to be precursors of vitamin A. The most well-known carotene is the aforementioned beta-carotene, cleaved by an enzyme in the intestinal mucosa to yield vitamin A.

Xanthophylls are the yellow-orange colored derivatives of carotenes containing carbon, hydrogen, and oxygen. Xanthophylls include lutein and zeaxanthin.

Autumn leaves show evidence of destruction of the green chlorophyll pigment, as the carotenes, and “autumn xanthophylls” that existed along with the chlorophyll become visible. Corn contains the xanthophyll *cryptoxanthin*, and green leaves contain *lutein*. Paprika also contains xanthophyll pigment.

The carotenoid pigment may undergo autoxidation due to the large number of double bonds. This oxidation may result in “off-flavor” and color loss, yielding unsatisfactory products. Antioxidants such as butylated hydroxy anisole (BHA), butylated hydroxy toluene (BHT), or tertiary butylated hydroxy quinone (TBHQ) are frequently added to a wide variety of foods containing fruits and vegetables, herbs, or spices to prevent this detrimental oxidation.

The FDA does not allow health claims for spices. However supportive research into the health benefits of spices fits nicely into two consumer trends: movement toward natural remedies and a growing appetite for spicy foods. (Hazen 2012)

Whereas *oxidation* causes development of a *lighter-color* cooked vegetable, *caramelization* of plant sugar may result in a *darker-color* cooked vegetable. It is recommended that

carotene-pigmented vegetables should be either covered during cooking, or cooked quickly, as in stir-frying. Since the pigment is fat soluble, table fat such as butter or margarine should be minimized or omitted in cooking as the pigment may become paler.

The length of cooking time does *not* negatively affect carotenoid pigments as much as it does for chlorophyll, and changes are *not* as noticeable. However, upon *heating*, and in the presence of *acid*, some molecular isomerization occurs. Specifically, in carotenoids, the predominant *trans* molecular form, naturally present in plants, is changed to *cis* configuration in a matter of a few minutes, and the pigment becomes less bright. Unlike the case with chlorophyll pigments, *alkali* environments do *not* produce a color change.

Carotenes provide color in food. Food technologists have developed annatto, carrot, paprika, and tomato *extracts* to provide color in foods. (Pinkish-white flowers of the annatto plant with their small reddish-orange seeds inside offer dye used to color foods such as cheddar cheese.)

In addition to the plant pigments, added herbs and spices also provide carotene coloring and flavor. Albeit in *small* amounts in foods, they contribute to vitamin A values that appear on nutrition labels. They supply advantageous nutrients such as beta-carotene. This addition offers the same nutrients as a diet of yellow, green, and leafy vegetables, although in significantly lesser amounts.

Carotene from vegetables or fruits may prevent oxidation of body tissues, and development of *cancer*, although much remains unknown about possible benefits of *supplements* of this biologically active component of plant material. The Academy of Food and Nutrition advocates *foods* in the diet as the best source of good nutrition (see “Nutritive Value of Vegetables and Fruits” section rather than supplements).

CULINARY ALERT! Cooking change is minimal for carotenoids.

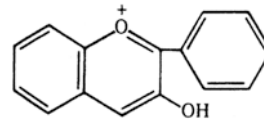


Fig. 7.4 Anthocyanin

Another group of pigmented compounds consisting of anthocyanins and anthoxanthins are the flavonoids.

Anthocyanin

Anthocyanin (Fig. 7.4) is the red, blue-red, blue, or purple pigment in fruits and vegetables such as blueberries, cherries, raspberries, red cabbage, red plums, and rhubarb (not beets; see “Betaines” section). The *skins* of radishes, red apples, red potatoes, grapes, and eggplant also contain anthocyanin pigment. It is prevalent in buds and young shoots, and is an underlying pigment of chlorophyll, that becomes apparent as a purplish pigment in autumn leaves when chlorophyll decomposes.

Anthocyanins contain a *positively charged oxygen* in the central group of the molecule and belong to the flavonoid group of chemicals. Thus they are distinguished from the orange-red found in carotenoids. These pigments are *water-soluble* and are found in the cell sap of plants. They may be released into the cooking water with soaking or prolonged heat exposure.

In the following is a discussion regarding anthocyanin and pH.

pH and color: Care must be taken when working with the anthocyanin pigments. Mixed fruit juices for a punch drink or fruits incorporated into baked goods with alkaline leavens may produce undesirable color. Either the addition of *alkali* or an alkaline cooking medium produces unwelcome violet-blue or turquoise color.

In an *acidic* environment, the anthocyanin pigment exhibits a more characteristic

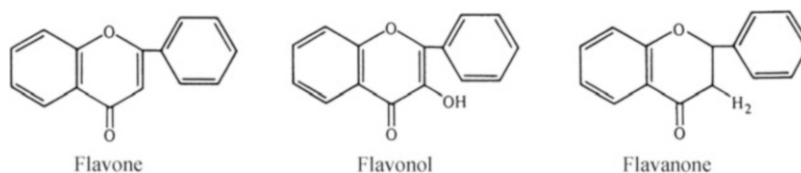


Fig. 7.5 Anthoxanthin

red color. A tart, acidic apple is often added to red cabbage while cooking in order to produce a more appealing finished product.

pH and texture: Textural characteristics are *also* affected by pH. If acids such as lemon juice or vinegar are added to fruits and vegetables (anthocyanin pigment) for better color, it should be *after* desired softening has occurred because acid prevents softening (see “Cooking Effect” section).

Recall the *negative* changes to the chlorophyll pigments when it is cooked *covered*, and still *retaining* plant acids. The opposite is true of anthocyanin pigmented vegetables. In fact, cooking the anthocyanin-pigmented vegetable *with* a cover is recommended for better color retention since *plant acids* are then *retained* yielding acidic cooking water. If fruits containing anthocyanins are added to batters and dough, such as in the preparation of blueberry muffins, *acidic* buttermilk is also incorporated to assist in preserving color. Color changes that occur in cooking are reversible.

Metals, such as iron from non-stainless-steel preparation tools, also change pigments. Metals can change the natural purplish pigment to a blue-green color. Therefore, food products containing the anthocyanin pigment are often canned in lacquer-coated (enamel-lined) metal cans to prevent the product acid from interacting with the can metal and causing undesirable color changes.

CULINARY ALERT! Anthocyanin color is subject to reversible changes in cooking.

Anthoxanthin

A fourth major pigment, *anthoxanthin* pigment (Fig. 7.5) is also a flavonoid, and is similar to anthocyanin, yet it exists in a *less* oxidized state, as the oxygen on the central group is *uncharged*. (Recall: anthocyanins contain a *positively charged oxygen*.) Anthoxanthins are white, or pale yellowish, *water-soluble* pigments found in a plant’s cell sap. This classification represents flavone, flavonol, flavanone, and flavanol pigments, and includes fruits such as apples, or vegetables such as cauliflower, onions, and potatoes.

A *short* cooking time is desired for the anthoxanthin pigment. Otherwise, with *prolonged* heat, the pigment turns into an undesirable brownish gray color. For example, white, anthoxanthin potatoes, with their low organic acid content, may become unfavorably dark colored after prolonged cooking due to formation of an iron–chlorogenic acid complex. Some anthoxanthins may *change* to anthocyanins and exhibit a pinkish tinge if vegetables are overcooked.

In *acid* environments, anthoxanthin becomes lighter. (Therefore, in household use, cooking in an acid environment, incorporating one teaspoon of cream of tartar per quart of water may be useful in lightening the color.) If cooking water is *alkaline* or contains traces of iron salts, the result may be a *yellow* or *brown* discoloration of white cooked vegetables. Cooking in aluminum cookware also causes the same negative discoloration.

CULINARY ALERT! Short cooking of the anthoxanthin pigment is advised. It remains whiter in acid.

Betalaines

Betalaines are a minor group of pigments that contain a nitrogen group in the molecular structure. They are similar to, yet *not* categorized as anthocyanins or anthoxanthins. These pigments differ in color.

For example,

- Betacyanines are **red-colored** like anthocyanins at a pH of 4–7
- Betaxanthines are **yellow-colored** like anthoxanthins at a pH above 10
- Betalaine below a pH of 4 is **violet-colored**

A lacquered can (as with anthocyanins) is used in order to prevent color changes that may result from metals in the can reacting with the betalaine pigment.

Tannins

Tannins (tannic acid) are polyphenolic compounds that add both color and astringent flavor to foods. They may be responsible for the *unwanted* brown discoloration of fruits and vegetables, as well as for the *desirable* changes that provide tea leaves with their characteristic color. They range in color from pale yellow to light brown, and due to their acidic nature, they tend to cause the mouth to pucker. (Astringents shrink mucous membranes, extract water, and dry up secretions.)

The term tannin represents a broad group of compounds found in plants—normally in bark, fruit, leaves, and roots. Tannins, such as the brownish pigment found in tea leaves may be used as the brown colored dye in dyeing fabrics or tanning leather. Food tannins found in wines, and teas, contain antioxidant properties correlated with good health. Tannins precipitate proteins causing

them to become a solid and “*settle*” out to the lower edge of a solute phase (however, proteins will *float* if they are less dense than the solvent).

Flavor Compounds

The flavor of cooked vegetables is greatly influenced by the presence of sulfur both *allium* and *brassica* compounds, although aldehydes, ketones, organic compounds, and alcohols are contributors to the flavor profile. Some of the favorable sulfur compounds, including allyl sulfides may increase excretion of carcinogens from the body, according to the American Cancer Society (ACS).

Allium

Vegetables of the genus *allium* include chives, garlic, leeks, onions, and shallots, each different members of the *lily* family. Onions, for example, contain strong sulfur compounds, and exhibit enzyme activity when cut, causing the eyes to tear (lachrymatory effect). Similarly, garlic undergoes an enzymatic change to sulfur compounds, precursor (+)-*S-allyl-L-cysteine sulf-oxide*, producing the identifiable garlic odor.

While these flavor compounds in plants are *water soluble*, they may be lost from the vegetable to the water, then volatilized as steam during cooking. It follows then, that if a *mild* flavor is desired in cooked onions, a *large* amount of boiling water and cooking *uncovered* for a long time period is recommended. In that manner, sulfur flavor compounds are degraded and vaporized. Inversely, a *sweeter, more concentrated* flavor is produced if *less* water and a *cover* is used. The most *intense* flavor results from cooking in fat where flavor is simply *not* lost.

CULINARY ALERT! Allium: is mild if vegetable is cooked in a large amount of water,

uncovered. A concentrated, stronger flavor is apparent if less water, and covered cooking is chosen. Intensity is greatest when cooking in oil.

Brassica

Vegetables of the genus *Brassica* include broccoli, Brussels sprouts, cabbage, cauliflower, kale, kohlrabi, mustard greens, rutabaga, and turnips. They are of the *mustard* family and are known as *cruciferous* vegetables that have a cross-shaped blossom on the young, growing plant. As opposed to allium, the *naturally mild* flavor of the *raw* vegetables with brassica *becomes quite strong* and objectionable with prolonged *cooking* as hydrogen sulfide is produced.

That is why, for optimal flavor of *brassica* flavored vegetables, a *small* amount of briskly boiling cooking water and *short* cooking is advised. Also, in order to allow the volatile organic acids to escape, it is recommended that the vegetables should be *uncovered* at the beginning of the cooking process. Then they may be *covered* to keep the cooking time short.

Several vegetables of the Brassica genus, such as cabbage, contain a sulfur compound known as *sinigrin*. Sinigrin may interact with an enzyme, myrosinase released from the cut or bruised cell and produce potent mustard oil. *The (+)-S-methyl-L-cysteine sulfoxide* compound may convert to the more desirable dimethyl disulphide.

CULINARY ALERT! Brassica: cooking in a small amount of water, for a short time, with a cover, prevents development of an unacceptable strong flavor.

Organic Acids

Organic acids give the tart, sour taste of fruits, and they include some of the following acids—citric acid, malic acid, or tartaric acid. *Vegetables* contain a greater variety of organic acids, yet maintain a less acidic pH level than fruits.

Concentrates, Extracts, Oils, Spices, and Herbs

Concentrates, extracts, oils, spices, and herbs incorporate flavor into food as it is processed. These may be used as an alternative to fresh, frozen, or dehydrated vegetables in a product formulation and they provide products with a pure, consistent quality of flavor when they are added. *Concentrates* impart the vegetable's characteristic flavor. *Natural plant extracts* may be used to yield the flavors and aroma of fresh herbs and spices. *Essential oils* are also removed from a plant and concentrated to produce flavoring oils. These may be the replacement for some spices and herbs.

Although there may not be a clear-cut distinction between an herb and spice, a herb is generally from the *herbaceous* part of plants. According to the American Spice Trade Association (ASTA), a spice is “any dried plant product used primarily for seasoning purposes.” Spices may come from fruits, flowers, roots, or seeds, as well as from shrubs and vines. They enhance color, flavor, palatability, and they exhibit antimicrobial properties (Sherman & Flaxman 2001). (The Food and Drug Administration (FDA) does not include dehydrated vegetables in its definition of spices, but rather they are “flavors.”)

An immense amount of folklore goes along with herbs and spices, which may be used for medicinal as well as culinary purposes. While *traditional medicine* in practice for centuries, includes the use of herbs and spices, such traditional medicine may be combined in practice *today* with *Western or modern medicine*. In fact, the *National Center for Complementary and Alternative Medicine*, established by the *National Institutes of Health*, has as its mission to seek out effective and alternative medical treatment, to evaluate the outcomes, and report findings to the public!

Vegetable Classifications

Vegetable classifications demonstrate the parts of the plant eaten as food. This varies throughout the world. The eight common parts, beginning with underground parts of the plant and progressing to those parts growing above ground, are as follows:

- **Roots**—underground; beet, carrot, jicama, parsnips, radish, rutabaga, sweet potato, turnip, yam (“Sweet potatoes” are a yellow to orange color flesh, either dry or moist. In the USA, they may be known as “yams,” and both names are stated on a label. The non-orange, true “yam” is yellow, white, or purple-pigmented flesh root vegetables)
- **Tubers**—underground; enlarged fleshy stem; starch storage area after leaves manufacture carbohydrates; buds or eyes form new plants; Irish potato, Jerusalem artichoke
- **Bulbs**—stems with an underground bulb of food reserve; garlic bulb, leeks, onions, shallots, spring onions (green onions or scallions do not possess a real bulb)
- **Stems**—a plant’s vascular system, nutrient pathway; a lot of cellulose; asparagus, celery, kohlrabi, rhubarb
- **Leaves**—the manufacturing organ for carbohydrate that is then stored elsewhere in the plant; Brussels sprouts, cabbage, lettuce, parsley, spinach; also seaweed and “greens” such as beet, collards, kale, and mustard greens
- **Flowers**—clusters on the stem; artichoke, broccoli, cauliflower
- **Fruits**—the mature ovaries with seeds, generally sweet, and fleshy; apple, banana, berry, and orange; although including vegetable-fruits, such as

avocado, cucumber, eggplant, okra, olive, pepper, pumpkin, snap beans, squashes, and tomato that are not sweet, and seeds

- **Seeds**—in fruit of a plant; may be in pods; includes legumes such as dried beans, peas, and peanuts, and, in the USA, sweet corn (although it is a grain, not vegetable); may be sprouted

Harvesting and Postharvest Changes

Harvesting and postharvest processing *schedules* and *procedures* should be strictly followed to ensure fruits and vegetables with the highest possible quality. Crops are harvested at *different* stages of maturity prior to storage, and they are likely to be larger and less tender with age. It may be ideal to harvest *less mature* fruits and vegetables, *or* to allow them to “ripen on the vine.”

Another ideal practice is that of *cooling* fresh produce *in the field*, and then canning *close* to the field, prior to transport. This practice minimizes negative changes in quality.

After harvest, fruits and vegetables continue to undergo respiration, the metabolic process of taking in oxygen (O₂) and giving off carbon dioxide (CO₂), moisture, and heat. The maximum rate of respiration occurs just before full ripening. *Climacteric* fruits, such as the apple, apricot, avocado, banana, peach, pear, plum, and tomato ripen *after* harvesting. Tropical fruits such as the papaya and mango are also climacteric, as is the avocado.

On the other hand, *non-climacteric fruits*, such as the cherry, citrus fruit, grapes, melon, pineapple, and strawberry ripen *prior* to harvest.

- Climacteric—ripens AFTER harvesting

- Non-climacteric—ripens BEFORE harvesting

Natural postharvest sunlight, artificial, or fluorescent light exposure may form a green chlorophyll pigment and *solanine* (bitter, and toxic at high levels) in some vegetables such as onions or potatoes. Green colored spots may appear just below the skin, and if small, these small amounts may easily be cut away.

Proper packaging for shipping is significant. Storage conditions that retain plant's moisture or heat reduce negative changes in the fruit or vegetable, such as undesirable mold or rot.

Ripening

Evidence of ripening can be *seen* and felt to the touch in a physical evaluation. For example, changes from the green color (due to chlorophyll degradation) allow more carotenoid pigment to be visible in the fruit as it ripens. Flavor changes are noted with an *increase* in the sugar and *decrease* in the acid content.

Between the produce maturity and ripening, there is a lot of unseen enzymatic activity. Although ripening may be *unseen*, there is internal hormonal and enzyme activity prior to change in the physical appearance.

A *noticeable* ripening change that occurs is due to the production of odorless and colorless ethylene gas. For example, the emission of this gas generates a softening of the plant cell wall. *Ethylene gas* is a naturally occurring hydrocarbon produced by some vegetables and fruits, especially apples, bananas, citrus fruit, melon, and tomatoes. In particular, lettuce and leafy vegetables as well as any bruised fruits are especially susceptible to undesirable respiration due to the presence of ethylene gas. Storage conditions should *separate* ethylene producers from other fruits that do not require ripening. (“*One bad apple spoils the whole bunch!*”)

In addition to *natural* ethylene gas, there is also *artificially* produced ethylene gas, made by the burning of hydrocarbons. Food distributors may introduce measured doses of ethylene gas into a closed food chamber for the purpose of ripening unripened fruits before they are sold to retailers. The effectiveness of ethylene in achieving faster and more uniform ripening is dependent on the pulp temperature and stage of maturity of the fruit, and the relative humidity of the ripening room ([SYSCO Foods](#)).

CULINARY ALERT! A technique for ripening fruit at home is to place unripened fruit in a closed paper bag, which then traps ethylene gas and speed up desirable ripening.

There is some control for the unwanted effects of natural ethylene gas, which may overripen the fruit and result in poor quality. Specifically, *gibberellic acid* may be added as a control to the external storage environment of fruits and vegetables. A preharvest application of this plant growth regulator delays ripening, and retains firmness in a fruit, both of which are important considerations in postharvest handling, storage, and transportation.

In the process of *senescence* (overripening), the intracellular protopectin develops into water-soluble pectin. *Overripe* fruits and vegetables become soft or mushy as the once-firm cells separate from one another. To control unwanted ripening and extend shelf life, edible waxes and other treatments, including irradiation treatment, may be applied to fruits and vegetables. The enzymes, sucrose synthetase and pectinase, are used in measuring maturity of *some* potatoes and fruits.

Refrigeration may reduce adverse chemical reactions. As well, manipulation of CO₂ and O₂ through controlled atmosphere storage (CA), controlled atmosphere packaging (CAP), and modified atmosphere packaging (MAP) offers control of ripening (Chap. 19).

Enzymatic Oxidative Browning

Enzymatic oxidative browning (EOB) occurs when the plant's phenolic compounds react with enzymes in the presence of oxygen. When bruised or cut during preparation, discoloration of *some* fruits or vegetables may occur. For example, when some varieties of apples, apricots, bananas, cherries, peaches, pears, eggplant, or potatoes are bruised or cut, the product *enzymes* are exposed to *oxygen* in the atmosphere, and the produce is subject to undesirable *browning* or *EOB*.

Control measures to prevent EOB may not be easy. For example, there may be more than one substrate existing in a fruit or vegetable, also, oxygen may come from intercellular spaces, not solely surface air, and then the responsible enzyme must be denatured. Damaging enzymes spread in storage, and as mentioned earlier, it is true that "one bad apple spoils the whole bunch!"

One effective control of browning is to avoid contact between the substrate and oxygen. In order to achieve this, food may be covered with a *sugar syrup* in order to block oxygen, or it may be covered with a film wrap that limits oxygen permeability. Another control is the application of a commercially prepared *citric acid powder* or *ascorbic acid* to the cut fruit surface. Lemon juice in a ratio of 3:1 with water may be applied to the surface of the fruit, according to the Produce Marketing Association. In this manner, the vitamin C juice is oxidized *instead* of the pigment, and the acidic pH inhibits enzymatic action.

Pineapple juice, because of its sulfhydryl groups (–SH) acts as an antioxidant, and is an *additional*, effective means of protection against browning. (As with lemon juice, the Produce Marketing Association recommends dipping cut fruits in pineapple juice [3:1 ratio, pineapple juice to water] for controlling EOB.) Sulfur compounds in the juice interfere with the darkening of various foods, such as cut fruit, cut lettuce leaves, and white wine. However, due to health concerns of a small percentage of the population allergic to sulfites, the use of sulfiting

agents to prevent browning is restricted in raw products. Other available agents may be used.

Home gardeners usually blanch fruits or vegetables prior to freezing. *Blanching* destroys the polyphenol oxidase enzyme and enables the product to withstand many months of freezer storage *without* degradation. Blanching entails the placement of (usually) cut-up fruit or vegetable pieces in boiling water for a precise period of time prior to freezing. The exact length of time depends on the volume and texture of the product.

CULINARY ALERT! To control browning, avoid contact between the substrate and oxygen—cover susceptible fruit with a sugar syrup or film wrap. Cover or immerse cut fruit in lemon juice, orange juice, pineapple juice, or a commercial treatment to control browning.

Cooking Effect

Cooking has many effects on food—its water retention, color, texture, flavor, and nutritive value to name a few of the effects. When short cooking periods and cooking methods such as steaming are selected, the effect is minimal loss of both flavor and nutritive value. Also, steaming retains the natural color as it does not allow contact between released internal acids and the food.

Vegetables and fruits may be consumed raw, without cooking, or are made ready for consumption by methods such as baking, boiling, frying, pressure-cooking, sautéing, steaming, stir-frying, and so forth. Cooking introduces appearance and texture changes, as well as flavor and nutritive value changes, as shown in the following.

Water Retention/Turgor

Water retention and turgor are changed once a fruit or vegetable is cooked. Once cooked, the cell membranes *lose* their selective permeability, and unlike the simple movement of water/osmosis that

occurs in *raw* produce, the *cooked* cell membranes allow the additional movement of sugars and some nutrients as well as water. *Diffusion* occurs as substances move from an area of higher concentration to an area of lower concentration and the plant cell loses its form, water, and turgor.

Color

The natural color of *raw* fruits and vegetables varies, and the color of *cooked* fruits and vegetables is influenced by a number of factors as previously discussed in this chapter. These factors include the natural plant pigment and pH, age, duration of cooking, use of a pan lid, cooking method employed, and surrounding environment. *Blanching* serves to inactivate enzymes and expel intercellular air that may negatively affect color.

Cooking in aluminum or cast-iron cookware may *negatively discolor* cooked products, therefore, instead, the use of stainless steel may be recommended for cooking vegetables or fruits. Another color change accompanies the use of sodium bicarbonate, which yields a *brighter green* color. However, as earlier mentioned, this usage is not recommended, as vitamin and texture losses occur.

Texture

Without doubt, the *texture* of a fruit or vegetable changes upon cooking. The texture of the cooked vegetable depends on a number of factors. These factors include pH, age, duration of cooking, and water composition. For example, lengthy cooking in boiling *alkaline* water drastically softens texture as hemicelluloses break down; cellulose is softened, and pectins degrade. The addition of *acid*, such as the addition of a tomato to another vegetable recipe, yields a firm cooked vegetable because tissues do not soften, and pectin precipitates.

Helping to retain texture are calcium ions. These calcium ions are *naturally* present in hard

water or may be *added* to many canned vegetables in commercial processing. For example, canning tomatoes with the addition of calcium *retains* the texture of cooked plant tissue forming insoluble salts with pectic substances. For a similar reason, brown sugar or molasses are common additives that are useful in retaining texture as well—e.g., Boston Baked Beans. Of course, the texture is also related to maturity of the plant, which may become tougher and “woody” due to the presence of lignin in older plants.

Flavor

The flavor of cooked vegetables is dependent on factors such as the classification as either *Allium* or *Brassica*, and loss of both water-soluble organic acids and sugars from the vacuole. Additionally, recipe ingredients including sugar, fat, herbs, and spices vary the flavor of vegetables and may actually encourage a wary person to eat the vegetables!

Nutritive Value

Nutritive value is presented in much more detail *later* in this chapter. For now, discussion is limited to *cooking effect* on nutritive value. The nutritive value of cooked fruits and vegetables is influenced by factors such as nutrients naturally present in the food, the type of cooking medium, duration of cooking and added substances. Through diffusion, water-soluble *vitamins and sugars* in the cell sap are lost from parenchyma cells and may be oxidized. On the other hand, *minerals* present in plant material are inorganic substances that cannot be destroyed (although they may be discarded in fruit or vegetable trimmings).

Of nutritional benefit in cooking is a *short cooking* time in a *minimal* amount of water or *steaming* the vegetables. Yet, there are times when just the opposite, that is, *lengthy cooking*, with *plentiful* water may be desirable to achieve mild taste—foods such as mild tasting cooked onions may benefit from lengthy cooking and plentiful water.

Regarding the use of lids, it may be beneficial to cook *with a pan lid on* since it speeds up cooking and leads to the *desirable* retention of acids, flavor, or nutrients. Recall however, cooking with a *lid on* for the entire duration of cooking is *detrimental* to the green chlorophyll pigment and *Brassica* flavored vegetables as has been described.

CULINARY ALERT! Cooking produces changes in the turgor, appearance, texture, flavor, and nutritive value. Some changes are desirable, some not! Cook vegetables minimally.

Fruits—Unique Preparation and Cooking Principles

In this portion of the chapter, attention is given to some of the unique aspects of cooking and preparing *fruits*. Further discussion of “fruits” in this section may include vegetable-fruits such as avocados and peppers, yet most typically, fruit is referring to sweet, fleshy fruits containing seeds. It should be kept in mind that bananas and seedless grapes are examples of *fruits without seeds*.

To repeat a previously mentioned concept, the *botanical* definition of a fruit includes all grains, legumes (beans and peas), nuts, as well as some plant parts commonly eaten as “vegetables” (i.e., tomatoes) and thus is different from the culinary definition. According to its *culinary* role, fruit is the sweet, fleshy part of a plant, usually eaten alone or served as dessert. Grains, legumes, and nuts do not fit into this culinary definition of fruit; neither do the “vegetable-fruits” such as avocados, cucumbers, eggplant, okra, olives, peppers, pumpkin, snap beans, squash, and tomatoes, which are typically considered as *vegetables* in dietary regimes. The following is interesting:

A 1893 tax dispute led to the ruling by the United States Supreme Court that a tomato was a vegetable. “Botanically, tomatoes are considered a fruit of the vine, just as are cucumbers, squashes, beans, and peas. But in common language of people, whether sellers or consumers of provisions, all these are vegetables which are grown in kitchen gardens, and which, eaten cooked or raw, are, like

potatoes, carrots, parsnips, turnips, beets, cauliflower, cabbage, celery, and lettuce, usually served at dinner in, with, or after the soup, fish, or meats which constitute the principal part of the repast, and not like fruits, generally, as dessert” (United States Supreme Court) (Cunningham 2002).

Fruit Preparation

During fruit preparation, *water loss* may occur. For instance, when fresh-cut strawberries are sprinkled with sugar for added flavor, water is lost from the fruit through osmosis, and red (sweetened) liquid can be seen collecting in the bowl of strawberries. Other fruits may show the same effect or undergo *discoloration* due to EOB.

Whether prepared commercially by Industry, by a foodservice establishment or at home, cooking fruit in different manners/mediums may occur as follows:

Water: When fruits are cooked in *plain water*, water moves into the tissues (*osmosis*), and sugar, at a 12–15 % level naturally, diffuses out (*diffusion*). The fruit, including dried fruit, such as raisins, becomes plump. Pectins become soluble and diffuse into water; cells become less dense, and the product becomes tenderer. Cellulose is softened, and lignins remain unchanged. The fruit loses its shape.

Sugar addition: Sugar may be utilized in cooking. It offers flavor and some preservation. When *large* amounts of sugar (amounts greater than that found naturally in fruits) are added to the cooking water at the *beginning* of cooking, the tenderization is diminished and the *shape* will be *maintained*. This is because the water moves out, and the higher concentration of sugar outside of the piece of fruit moves in by diffusion. As well, the sugar interferes with plant pectin solubility. It also dehydrates cellulose and hemicellulose resulting in shrunken, tough walls.

Timing for the addition of sugar is significant. If sugar is added to fruit *early* in cooking, then that is desirable for berries or slices, where retaining shape is important. *Conversely*, when fruits are cooked in plain water and

sugar is added *late*, after cooked fruit *loses its shape* and softens, desirable fruit sauces such as applesauce are formed.

Flavor changes: There are flavor changes that occur in a fruit preparation method such as cooking fruit. Water-soluble sugars and other small molecules, escape to the surrounding water in cooking. Consequently, the cooked fruit tastes blander, unless sugar is added during cooking.

Fruit Juices and Juice Drinks

Fruit “Juices” are 100 % fruit by definition, while “juice drinks” must only contain 10 % or more of real juice. Each may be formulated from a variety of fruits. Data on yield and amounts of produce needed to extract juice becomes important in studies on diet and disease (Newman et al. 2002). The FDA requires that commercial juices be pasteurized to control microbial growth. Treatment with ultraviolet (UV) irradiation is given in order to reduce the pathogens and other detrimental microorganisms.

Grading Vegetables and Fruits

Grading by the United States government (USDA) is a *voluntary* function of packers and processors. It is *not* an indication of safety, nutritive value, or type of packs (e.g., “packed in heavy syrup” and so forth). Wholesalers, commercial, and institutional food service, including restaurants and schools, may purchase according to grade using written specifications, although consumers may be unaware of grading.

Dried and *frozen* forms of fruits and vegetables are graded, although grading indications appear *less* commonly than on *canned* or *fresh* products that often show grade. In the highly competitive wholesale food-service market, *canned* fruits and vegetables receive US Grade A, B, or C.

US Grade A is the *highest* rating and indicates the best appearance and texture, including clarity of liquid, color, shape, size, absence of blemishes

or defects, and maturity. US Grade C is the *lowest* grade. *Fresh* fruits and vegetables are rated US Fancy, US No. 1, and US No. 2.

Private labeling by some companies may have specifications that state a narrow range within a grade. Proprietary names may be assigned to various grades.

Organically Grown Vegetables and Fruits

“Organically grown” was formerly a term without a federal standard for the foods’ production, handling, and processing. Finally, in February 2001, the USDA provided a federal definition for “organically grown.” Rules for implementing The Organic Foods Production Act of 1990 took several years to go into effect and proposals were released for feedback several years prior to the final ruling. A tremendous amount of public input was obtained in an attempt to satisfy both the organic farmer and the consumer.

The intent of the final comprehensive Organic Foods standard was to *clarify* for the consumer. As well, it was to *ease potential confusion* in domestic and export sales, and make use of just *one* product label, eliminating the need for individual state and/or private standards. The USDA Organic Seal was also redesigned for better consumer understanding and became effective for use in August 2002.

Subsequent to legislation, foods labeled “organic” must be grown *without* the use of chemical pesticides, herbicides, or fertilizers (Wardlaw & Smith 2011) and have *verifiable records* of their system of production. Organic products must be 95 % organically produced; processed foods may be labeled “made with organic ingredients.” If organic production and handling is *not* followed, yet a product *is* offered for sale as organic, a large monetary fine may be imposed.

Even though there is the *absence* of chemical pesticides, herbicides, and fertilizers used during growth, which would be desirable to some individuals, there is *no* evidence that organically grown foods are *higher* in *nutrient* content than conventionally grown foods. A poor soil may

yield a lower crop, yet *not* one of lesser nutritive value (Newman et al. 2002).

While the *pesticide* residue would certainly be lowered or nonexistent, *bacterial counts* of organically grown plant material may be *higher* than conventionally grown foods. This is especially true if animal manure was used as a fertilizer, and care in washing was overlooked. Organically grown is *not* synonymous with *food safety* either, therefore, as with all produce, care must be taken to wash contaminants off all fruits and vegetables.

Of note in this discussion is the reminder that the National Organic Program (NOP) applies to *more than fruits and vegetables*. Crop standards, livestock standards, and handling standards are all addressed by the Act.

Biotechnology (More in Appendices)

Biotechnology (biotech) advocates say that biotech assists in providing a less expensive, safer, and better tasting food supply. Several years of conventional breeding techniques may be shortened by gene manipulation, possibly by half for some foods. Growers have strived to increase availability and yield of their crops, despite factors such as weather conditions in the growing region, insect infestation, and the lengthy time period of conventional breeding. It could be said that biotechnology goes back many centuries as a tool in breeding crops.

Biotech represents a combination of (a) conventional breeding, by plant breeders including selection, gene-crossing, and mutation, with (b) biotechnology, including recombinant DNA, and gene transfer. Continued collaboration between scientists using both approaches is needed in order to improve product quality and meet consumers' demands. Many consumers want to have genetically altered food products so-labeled.

The FDA ensures the safety of genetically altered foods and food ingredients in two ways, by regulating: *adulteration*, and by the *food additive* provision of the rules. These two FDA regulating methods provide the same safety

standards of any other *non-bioengineered* food product.

The following is a statement by the FDA Biotechnology Coordinator regarding food biotechnology:

Food biotechnology

First, let me explain what we mean when we refer to food biotechnology or genetically engineered foods. Many of the foods that are already common in our diet are obtained from plant varieties that were developed using conventional genetic techniques of breeding and selection. Hybrid corn, nectarines (which are genetically altered peaches), and tangelos (which are a genetic hybrid of a tangerine and grapefruit) are all examples of such breeding and selection. Food products produced through modern methods of biotechnology such as recombinant DNA techniques and cell fusion are emerging from research and development into the marketplace. It is these products that many people refer to as “genetically engineered foods.” The European Commission refers to these foods as Genetically Modified Organisms. The United States uses the term genetic modification to refer to all forms of breeding, both modern, i.e., genetic engineering, and conventional.

The new gene splicing techniques are being used to achieve many of the same goals and improvements that plant breeders have sought through conventional methods. Today's techniques are different from their predecessors in two significant ways. First, they can be used with greater precision and allow for more complete characterization and, therefore, greater predictability about the qualities of the new variety. These techniques give scientists the ability to isolate genes and to introduce new traits into foods without simultaneously introducing many other undesirable traits, as may occur with traditional

breeding. This is an important improvement over traditional breeding.

Second, today's techniques give breeders the power to cross biological boundaries that could not be crossed by traditional breeding. For example, they enable the transfer of traits from bacteria or animals into plants.

In conducting its safety evaluations of genetically engineered foods, FDA considers not only the final product but also the techniques used to create it. Although study of the final product ultimately holds the answer to whether or not a product is safe to eat, knowing the techniques used to create the product helps in understanding what questions to ask in reviewing the product's safety. That is the way FDA regulates both traditional food products and products derived through biotechnology.

Statement of:

James H. Maryanski, Ph.D., Biotechnology Coordinator

Center for Food Safety and Applied Nutrition
Food and Drug Administration

Before:

The Subcommittee on Basic Research,
House Committee on Science

FDA

Providing human and environmental *safety*, as well as *high-quality* foods, is of great significance to public. The FDA requires that all bio-engineered foods be labeled *if* they are significantly *different* from the original conventional food in nutritive value, or in posing food allergies.

Areas of research continue to focus on improving the areas previously mentioned. Certainly, the nutritive content of plant foods, such as improving the protein content of plants, and increasing their resistance to pests, or improving their storage is researched. In addition to providing the consumer with greater economy,

convenience, and improved nutritive value, safety is a factor that is important to both the grower and consumer. *Safety* of biotechnology has been debated and discussed by the public, educators, environmentalists, and scientists. The future may hold more such debate.

Historically, the safety of the first genetically engineered food designed for human consumption was demonstrated to the FDA and approval was granted for use of the Flavr-Savr tomato (in *May 1994*). Its shelf life was 10 days longer than other tomatoes. Due to the polygalacturonase (PG) enzyme, it stayed on the vine *longer*, thus it could be vine ripened with enhanced flavor. Then, in 1996, the planting of corn, potato, soybeans, and tomato varieties developed through *biotechnology* began following FDA decisions on safety. Currently many more food varieties are being developed through advances in biotechnology.

According to the International Food Information Council (IFIC), a significant component of the US harvest is produced by biotechnology (IFIC). In 10 years, during 2005, over 1,400 biotech notifications were acknowledged, and over 500 permits were approved (USDA).

The USDA's Agricultural Research Service (ARS) along with private industry and Academic research centers maintain the goal of developing improved genetic engineering. To date, there are some food companies that have ceased using, or announced that they will not use GMO's due to negative consumer reaction. The debate continues.

1. What is Agricultural Biotechnology?

Agricultural biotechnology is a range of tools, including traditional breeding techniques, that alter living organisms, or parts of organisms, to make or modify products; improve plants or animals; or develop microorganisms for specific agricultural uses. Modern biotechnology today includes the tools of genetic engineering.

2. How is Agricultural Biotechnology being used?

Biotechnology provides farmers with tools that can make production cheaper and more manageable. . . .

Researchers are at work to produce hardier crops that will flourish in even the harshest environments and that will require less fuel, labor, fertilizer, and water, helping to decrease the pressures on land and wildlife habitats. . . .

In addition to genetically engineered crops, biotechnology has helped make other improvements in agriculture not involving plants. Examples of such advances include making antibiotic production more efficient through microbial fermentation and producing new animal vaccines through genetic engineering for diseases such as foot and mouth disease and rabies.

USDA

For a more in-depth report on biotechnology and foods, see reports by the Institute of Food Technologists.

Irradiation

Irradiation is reported elsewhere in this text and in other writings. The aim is to control pathogens. There is much information available to learn beyond the scope of material in this text. Some fresh fruits, juices, and sprouts have also been treated in this manner. Plant seeds may be irradiated to control pathogens. On the horizon are the results of further studies seeking suitable methods to control pathogens in products other than fruits and vegetables.

According to the USDA “Food irradiation is a technology for controlling spoilage and eliminating foodborne pathogens.” The result is similar to pasteurization. The fundamental difference between food

irradiation and pasteurization is the source of the energy used to destroy the microbes. While conventional pasteurization relies on heat, irradiation relies on the energy of ionizing radiation.

“Food irradiation is a process in which approved foods are exposed to radiant energy, including gamma rays, electron beams, and x-rays. In 1963, the Food and Drug Administration (FDA) found the irradiation of food to be safe. . . . Irradiation is not a substitute for good sanitation and process control in meat and poultry plants. It is an added layer of safety”.



Radura Symbol

Vegetarian Food Choices

Vegetarian foods are chosen by a growing number of vegetarians, whether it is for religious, political, health, or other reasons. To clarify “vegetarian” is not simple, one must realize that it may indicate something different to various individuals. The meaning varies. However, true *vegans* are vegetarians who omit all animal products from their diet. If other types of vegetarian cuisines are followed, vegetarians might consume milk, or eggs, white meat, or fish. Persons adhering to consumption of minimal animal products are classified as “flexitarians.”

In view of the fact that *animal* products are the only significant source of vitamin B₁₂, vegans consuming a meat-less diet may be wise to obtain reliable, vitamin B₁₂ fortified foods. Vitamin B₁₂ supplementation may be chosen in order to maintain the myelin sheath surrounding the nerves and prevent permanent nerve damage and paralysis. It is valuable to note that microwave heating *inactivates* vitamin B₁₂ in foods (Chap. 9).

Labeling of Vegetables and Fruits

Nutrition Facts

Nutrition Facts labeling on foods in the USA must report on four items—vitamin A and C and the minerals, calcium and iron. These are identified below the solid line on all Nutrition Facts food labels. These four nutrients in particular are listed as nutrients that fall short of adequate levels for the population. Many Americans would do well to increase their intake of these two vitamins that are simultaneously so prevalent in fruits and vegetables. The label provides the consumer with information regarding the percentage of Daily Value that they are consuming in each serving. Individual fresh fruits and vegetables do not have labels, yet supermarket brochures, posters, or plastic bags relate the nutrient contribution.

Label Terms

Labeling terms that apply to fruits and vegetables include the following and must appear as a product descriptor after the product name, for example, “green beans, fresh”






- A “*Fresh*” food must be a raw food, alive, and respiring. Some skin surface treatment is acceptable, such as application of wax, or pesticides. Treatment with less than 1 kGy irradiation, to inactivate pathogenic and spoilage

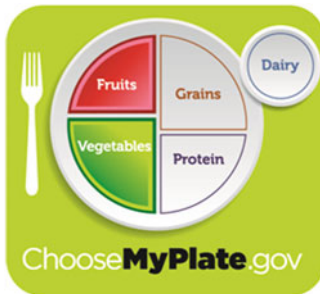
microorganisms is allowed. (The FDA is considering use of the term “fresh” for alternative nonthermal technologies that function to protect the US food supply, and clearly convey food characteristics to consumers.)

- “Freshly prepared” is food that has not been frozen, heat processed, or preserved.
- A “Good Source of” must contain 10–19 % of the Daily Value of that nutrient per serving.
- If an item states “Fat-free,” it must have less than 1/2 g of fat per serving. “Lowfat” indicates that the product must contain 3 g of fat or less per serving.
- Calorie level is important to many consumers. If an item states “Low-calorie,” it must contain less than 40 cal per serving.
- “Sodium-free” signifies that a product contains less than 5 mg of sodium (Na) per serving. “Very-low-sodium” is used for a product that contains less than 35 mg of Na per serving, and “Low-sodium” is less than 140 mg Na per serving.
- “High-fiber” is 5 mg or more of fiber per serving.

The 1991 nutrition labeling produce regulations were amended by the FDA. Regulations exist for labeling nutritive value of the 20 most frequently consumed vegetables and fruits. In addition to the top 20, other vegetables and fruits *must* be labeled if nutritional claims are made. Such labeling is *voluntary* and will continue to be voluntary if there is sufficient compliance noted by the FDA.

Nutritive Value of Vegetables and Fruits

				
Grains Group	Vegetable Group	Fruit Group	Dairy Group	Protein Foods Group
Make at least half your grains whole.	Vary your veggies.	Focus on fruits.	Get your calcium-rich foods.	Go lean with protein.



fresh, frozen, canned, or dried/dehydrated; and may be whole, cut-up, or mashed.

Vegetables are organized into five subgroups, based on their nutrient content.

Key Consumer Message: Vary your veggies. Make half your plate fruits and vegetables.

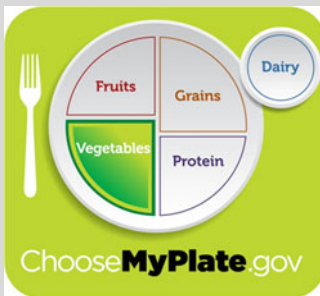
[View Vegetables Food Gallery](#)



(USDA)

ChooseMyPlate.gov

<http://www.choosemyplate.gov/food-groups/vegetables.html>



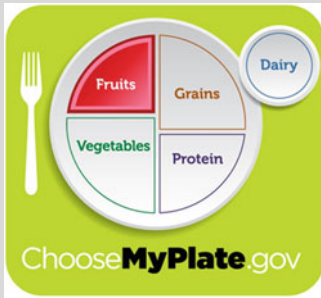
The *nutritional value* of vegetables and fruits is important in the diet. This text section is lengthy! Due to a worldwide supply and international purchasing potential, vegetables and fruits have year-round availability. Achieving good nutrition is enhanced by availability of the nutrients present in fruits and vegetables.

Vitamins, notably vitamins A and C, minerals (calcium and iron), and dietary fiber, are among the great benefits of a high fruit and vegetable diet, whether foods are canned, frozen, or fresh. As well, there are antioxidant properties (beta-carotene, vitamin C, and vitamin E), and anticarcinogenic properties, and fat is low for the majority of fruits and vegetables.

<http://www.choosemyplate.gov/food-groups/fruits.html>

What Foods Are in the Vegetable Group?

Any vegetable or 100 % vegetable juice counts as a member of the Vegetable Group. Vegetables may be raw or cooked;



Any fruit or 100 % fruit juice counts as part of the Fruit Group. Fruits may be fresh, canned, frozen, or dried, and may be whole, cut-up, or pureed. Some commonly eaten fruits are identified on the website.

Key Consumer Message: Focus on fruits. Make half your plate fruits and vegetables

[View Fruits Food Gallery](#)



Further dietary and medicinal benefits of fruits and vegetables are shown. For example, non-nutrients, such as the *phytochemicals* (phyto = plant) in fruits and vegetables, may function in

the prevention of human disease. This further supports the idea that nutrition is obtained from food rather than isolated compounds. Isolated compounds of fruits, vegetables, and other foods that are thought to provide health and medicinal benefits to the diet are *nutraceuticals*. The FDA has not recognized the term nutraceuticals or allowed health claims on products beyond those that are supported by the scientific community (Chap. 20, Appendix).

Additional evaluation and research is needed in order to address the many potential health benefit/disease-preventing properties of plant material. Some nutrition facts are included in Figs. 7.6 and 7.7.

Unfortunately, the USDA Department of Health and Human Services has noted: “In this land of plenty, millions of Americans aren’t eating wisely. Not because they haven’t had enough to eat, but because they eat too many of the wrong things or too little of the right.”

According to the American Diabetic Association Exchange List, one serving of vegetables contains 25 cal and one serving of fruit contains 60 cal.

“Vary your veggies” and “focus on fruits” is the USDA advice in selecting vegetables and fruits as part of a healthy diet.

Citrus fruits contain antioxidants, vitamin C, and relatively good amounts of folic acid that has been shown to prevent reoccurrence of neural tube defect in pregnant women. The FDA allows a label claim regarding foods with dietary fiber and a reduction of cancer incidence.

Taste is the most important factor that influences food choices; positive messages about benefits of diets with plenty of fruits and vegetables help with making choices. On a regular basis, the American Public eats too little of fruits and vegetables containing nutrients, such as vitamins A and C (on all Nutrition Facts labels), or the antioxidant vitamin E, all of which have an important role in preventing or delaying major degenerative diseases of Americans.

VEGETABLES

NUTRI-FACTS

UPDATE

NUTRITION FACTS FOR RAW VEGETABLES ¹																
Nutrient	% Daily Value of Nutrient	Nutrient														
		Calories	Calories From Fat	Total Fat	Sodium	Potassium	Total Carbohydrate	Dietary Fiber	Sugars	Protein	Vitamin A	Vitamin C	Calcium	Iron		
Vegetables, Serving portion (gram weight/ounce weight)		(g/%DV)	(mg/%DV)	(mg/%DV)	(g/%DV)	(g/%DV)	(g)	(g)	(%DV)	(%DV)	(%DV)	(%DV)	(g)	(g)	(g)	
Asparagus , 5 spears (93 g/3.3 oz)	25	0	0	0	230	7	4	1	2	8	2	2	10	15	2	2
Bell Pepper , 1 medium (148 g/5.3 oz)	30	0	0	0	270	8	7	2	2	8	4	1	8	190	2	2
Broccoli , 1 medium stalk (148 g/5.3 oz)	45	0	0.5	55	540	15	8	3	5	20	3	5	15	220	6	6
Carrot , 7" long, 1 1/4" diameter (78 g/2.8 oz)	35	0	0	40	280	8	8	3	2	8	5	1	270	10	2	0
Cauliflower , 1/6 medium head (99 g/3.5 oz)	25	0	0	30	270	8	5	2	2	8	2	2	0	100	2	2
Celery , 2 medium stalks (110 g/3.9 oz)	20	0	0	100	350	10	5	2	2	8	0	1	2	15	4	2
Cucumber , 1/3 medium (99 g/3.5 oz)	15	0	0	0	170	5	3	1	1	4	2	1	4	10	2	2
Green (Snap) Beans , 3/4 cup cut (83 g/3.0 oz)	25	0	0	0	200	6	5	2	3	12	2	1	4	10	4	2
Green Cabbage , 1/12 medium head (84 g/3.0 oz)	25	0	0	20	190	5	5	2	2	8	3	1	0	70	4	2
Green Onion , 1/4 cup chopped (25 g/0.9 oz)	10	0	0	5	70	2	2	1	1	4	1	0	2	8	0	0
Iceberg Lettuce , 1/6 medium head (89 g/3.2 oz)	15	0	0	10	120	3	3	1	1	4	2	1	4	6	2	2
Leaf Lettuce , 1 1/2 cups shredded (85 g/3.0 oz)	15	0	0	30	230	7	4	1	2	8	2	1	40	6	4	0
Mushrooms , 5 medium (84 g/3.0 oz)	20	0	0	0	300	9	3	1	1	4	0	3	0	2	0	2
Onion , 1 medium (148 g/5.3 oz)	60	0	0	5	240	7	14	5	3	12	9	2	0	20	4	2
Potato , 1 medium (148 g/5.3 oz)	100	0	0	0	720	21	26	9	3	12	3	4	0	45	2	6
Radishes , 7 radishes (85 g/3.0 oz)	15	0	0	25	230	7	3	1	0	0	2	1	0	30	2	0
Summer Squash , 1/2 medium (98 g/3.5 oz)	20	0	0	0	260	7	4	1	2	8	2	1	6	30	2	2
Sweet Corn , kernels from 1 medium ear (90 g/3.2 oz)	80	10	1	0	240	7	18	6	3	12	5	3	2	10	0	2
Sweet Potato , medium, 5" long, 2" diameter (130 g/4.6 oz)	130	0	0	45	350	10	33	11	4	16	7	2	440	30	2	2
Tomato , 1 medium (148 g/5.3 oz)	35	0	0.5	5	360	10	7	2	1	4	4	1	20	40	2	2

Most fruits and vegetables provide negligible amounts of saturated fat and cholesterol.

¹ Raw, edible weight portion. Percent Daily Values are based on a 2,000 calorie diet.

Developed by: Food Marketing Institute, American Dietetic Association, American Meat Institute, Food Distributors International, National Broiler Council, National Cattlemen's Beef Association, National Fisheries Institute, National Grocers Association, National Turkey Federation, Produce Marketing Association, United Fresh Fruit and Vegetable Association



Data Source: U.S. Food and Drug Administration

(7/96)

Fig. 7.6 Vegetables nutri-facts (Data Source: US Food and Drug Administration Developed by: Food Marketing Institute et al.)

FRUITS

NUTRI-FACTS

UPDATE

NUTRITION FACTS FOR RAW FRUITS¹

Nutrient % Daily Value of Nutrient	Calories		Colories From Fat		Total Fat	Sodium	Potassium	Total Carbohydrate	Dietary Fiber	Sugars	Protein	Vitamin A	Vitamin C	Calcium	Iron
	(g)	(%)	(g)	(%)	(g)	(mg)	(mg)	(g)	(g)	(g)	(g)	(%)	(%)	(%)	(%)
FRUIT , Serving portion (gram weight/ounce weight)															
Apple , 1 medium (154 g/5.5 oz)	80	0	0	0	0	170	22	5	20	16	0	2	8	0	2
Avocado , California, 1/5 medium (30 g/1.1 oz)	55	45	5	8	0	170	3	3	12	0	1	0	4	0	0
Banana , 1 medium (126 g/4.5 oz)	110	0	0	0	0	400	29	10	16	21	1	0	15	0	2
Cantaloupe , 1/4 medium (134 g/4.8 oz)	50	0	0	25	1	280	12	4	4	11	1	100	80	2	2
Grapefruit , 1/2 medium (154 g/5.3 oz)	60	0	0	0	0	230	16	5	24	10	1	15	110	2	0
Grapes , 1 1/2 cups (138 g/4.9 oz)	90	10	1	2	0	270	24	8	4	23	1	2	25	2	2
Honeydew Melon , 1/10 medium melon (134 g/4.8 oz)	50	0	0	35	1	310	13	4	4	12	1	2	45	0	2
Kiwifruit , 2 medium (148 g/5.3 oz)	100	10	1	2	0	480	24	8	16	16	2	2	240	6	4
Lemon , 1 medium (58 g/2.1 oz)	15	0	0	5	0	90	5	2	4	1	0	0	40	2	0
Lime , 1 medium (67 g/2.4 oz)	20	0	0	0	0	75	7	2	8	0	0	0	35	0	0
Nectarine , 1 medium (140 g/5.0 oz)	70	0	0.5	1	0	300	16	5	8	12	1	4	15	0	2
Orange , 1 medium (154 g/5.5 oz)	70	0	0	0	0	260	21	7	28	14	1	2	130	6	2
Peach , 1 medium (98 g/3.5 oz)	40	0	0	0	0	190	10	3	8	9	1	2	10	0	0
Pear , 1 medium (166 g/5.9 oz)	100	10	1	2	0	210	25	8	16	17	1	0	10	2	0
Pineapple , 2 slices, 3" diameter, 3/4" thick (112 g/4 oz)	60	0	0	10	0	115	16	5	4	13	1	0	25	2	2
Plums , 2 medium (132 g/4.7 oz)	80	10	1	2	0	220	19	6	8	10	1	6	20	0	0
Strawberries , 8 medium (147 g/5.3 oz)	45	0	0	0	0	270	12	4	16	8	1	0	160	2	4
Sweet Cherries , 21 cherries; 1 cup (140 g/5.0 oz)	90	0	0.5	1	0	300	22	7	12	19	2	2	15	2	2
Tangerine , 1 medium (109 g/3.9 oz)	50	0	0.5	1	0	180	15	5	12	12	1	0	50	4	0
Watermelon , 1/18 medium melon; 2 cups diced pieces (280 g/10.0 oz)	80	0	0	10	0	230	27	9	8	25	1	20	25	2	4

¹ Raw, edible weight portion. Percent Daily Values are based on a 2,000 calorie diet.

Most fruits and vegetables provide negligible amounts of saturated fat and cholesterol; avocados provide 1g of saturated fat per ounce.

Developed by: Food Marketing Institute, American Dietetic Association, American Meat Institute, Food Distributors International, National Broiler Council, National Cattlemen's Beef Association, National Fisheries Institute, National Grocers Association, National Turkey Federation, Produce Marketing Association, United Fresh Fruit and Vegetable Association

Data Source: U.S. Food and Drug Administration

(7/96)

Fig. 7.7 Fruits nutri-facts (Data Source: US Food and Drug Administration Developed by: Food Marketing Institute et al.)

The Academy of Nutrition and Dietetics (Position of The Academy of Nutrition and Dietetics) states that eating a wide variety of foods, including an emphasis on grains, vegetables, and fruits is the best way to obtain adequate amounts of beneficial food constituents: “It is the position of The American Dietetic Association that the best nutritional strategy for promoting optimal health and reducing the risk of chronic disease is to obtain adequate nutrients from a variety of foods. Vitamin and mineral supplementation is appropriate when well-accepted, peer-reviewed scientific evidence shows safety and effectiveness.” (Position of The Academy of Nutrition and Dietetics)

Nutrition continues to drive decision making in supermarket aisles across the country, according to *Shopping for Health* 2012, the 20th in a yearly study released today by the Food Marketing Institute (FMI) and *Prevention*, and published by Rodale Inc. (Prevention Magazine and Food Marketing Institute 2012)

[FMI conducts programs in public affairs, food safety, research, education, and industry relations on behalf of its nearly 1,250 food retail and wholesale member companies in the USA and around the world. FMI’s US members operate more than 25,000 retail food stores and almost 22,000 pharmacies with a combined annual sales volume of nearly \$650 billion. FMI’s retail membership is composed of large multi-store chains, regional firms, and independent operators. Its international membership includes 126 companies from more than 65 countries. FMI’s nearly 330 associate members include the supplier partners of its retail and wholesale members].

It is interesting to note that *The American Dental Association* recommends eating fruits such as apples and oranges and many uncooked vegetables such as carrots and celery. These act as “detergent” foods, cleaning teeth, and gums of food debris that may otherwise lead to the major nutrition-related problem of tooth decay.

Nutrient Losses

Nutrient losses may result from:

- Ascorbic acid (vitamin C) and thiamin (B₁) diffused to the water and oxidized.
- Mineral salts lost in soaking or cooking water.
- Excessive peel removal.
- Excessive chopping.
- Prolonged or high temperature storage.

Storage:

- Succulents, and leafy fruits and vegetables—stored covered in the refrigerator.
- Tubers—stored in a dark, cool place for quality.

10 tips
Nutrition
Education Series

add more vegetables
to your day



10 tips to help you eat more vegetables

It's easy to eat more vegetables! Eating vegetables is important because they provide vitamins and minerals and most are low in calories. To fit more vegetables in your meals, follow these simple tips. It is easier than you may think.

1 discover fast ways to cook
Cook fresh or frozen vegetables in the microwave for a quick-and-easy dish to add to any meal. Steam green beans, carrots, or broccoli in a bowl with a small amount of water in the microwave for a quick side dish.

2 be ahead of the game
Cut up a batch of bell peppers, carrots, or broccoli. Pre-package them to use when time is limited. You can enjoy them on a salad, with hummus, or in a veggie wrap.



3 choose vegetables rich in color
Brighten your plate with vegetables that are red, orange, or dark green. They are full of vitamins and minerals. Try acorn squash, cherry tomatoes, sweet potatoes, or collard greens. They not only taste great but also are good for you, too.

4 check the freezer aisle
Frozen vegetables are quick and easy to use and are just as nutritious as fresh veggies. Try adding frozen corn, peas, green beans, spinach, or sugar snap peas to some of your favorite dishes or eat as a side dish.

5 stock up on veggies
Canned vegetables are a great addition to any meal, so keep on hand canned tomatoes, kidney beans, garbanzo beans, mushrooms, and beets. Select those labeled as "reduced sodium," "low sodium," or "no salt added."



6 make your garden salad glow with color
Brighten your salad by using colorful vegetables such as black beans, sliced red bell peppers, shredded radishes, chopped red cabbage, or watercress. Your salad will not only look good but taste good, too.



7 sip on some vegetable soup
Heat it and eat it. Try tomato, butternut squash, or garden vegetable soup. Look for reduced- or low-sodium soups.

8 while you're out
If dinner is away from home, no need to worry. When ordering, ask for an extra side of vegetables or side salad instead of the typical fried side dish.

9 savor the flavor of seasonal vegetables
Buy vegetables that are in season for maximum flavor at a lower cost. Check your local supermarket specials for the best-in-season buys. Or visit your local farmer's market.



10 try something new
You never know what you may like. Choose a new vegetable—add it to your recipe or look up how to fix it online.

10 tips

Nutrition
Education Series

focus on fruits

10 tips to help you eat more fruits



Eating fruit provides health benefits. People who eat more vegetables and fruits as part of an overall healthy diet are likely to have a reduced risk of some chronic diseases. Fruits provide nutrients vital for health, such as potassium, dietary fiber, vitamin C, and folate (folic acid). Most fruits are naturally low in fat, sodium, and calories. None have cholesterol. Any fruit or 100% fruit juice counts as a part of the Fruit Group. Fruits may be fresh, canned, frozen, or dried, and may be whole, cut-up, or pureed.

1 keep visible reminders
Keep a bowl of whole fruit on the table, counter, or in the refrigerator.



2 think about taste
Buy fresh fruits in season when they may be less expensive and at their peak flavor. Add fruits to sweeten a recipe.



3 think about variety
Buy fruits that are dried, frozen, and canned (in water or 100% juice) as well as fresh, so that you always have a supply on hand.

4 don't forget the fiber
Make most of your choices whole or cut-up fruit, rather than juice, for the benefits that dietary fiber provides.



5 be a good role model
Set a good example for children by eating fruit every day with meals or as snacks.

6 include fruit at breakfast
At breakfast, top your cereal with bananas, peaches, or strawberries; add blueberries to pancakes; drink 100% orange or grapefruit juice. Or, try a fruit mixed with fat-free or low-fat yogurt.



7 try fruit at lunch
At lunch, pack a tangerine, banana, or grapes to eat, or choose fruits from a salad bar. Individual containers of fruits like peaches or applesauce are easy and convenient.

8 experiment with fruit at dinner, too
At dinner, add crushed pineapple to coleslaw, or include orange sections, dried cranberries, or grapes in a tossed salad.

9 snack on fruits
Dried fruits make great snacks. They are easy to carry and store well.



10 keep fruits safe
Rinse fruits before preparing or eating them. Under clean, running water, rub fruits briskly to remove dirt and surface microorganisms. After rinsing, dry with a clean towel.



Safety of Vegetables and Fruits

Safety is a food characteristic that the public expects. Foods should be safe, and in fact, the public is encouraged to eat more fruits and vegetables for health. Fruits and vegetables are *not* considered “potentially hazardous foods” that allow the “rapid and progressive growth of infectious or toxigenic microorganisms” (Model FDA Food Code).

In comparison to animal-based foods, there are few problems with plant-based products, yet, unfortunately, plant-based products can carry disease. Recently fresh, bagged spinach was pulled off the market nationwide, due to E-coli bacteria. Health Departments across the USA advised that washing the bagged spinach could not guarantee safety. One death and illness in many states followed ingestion of the spinach.

Pathogenic microorganisms are found in the environment and can contaminate food, causing illness. Imports from less-developed regions of the world may be implicated as a contributing factor in the increase in fruit- and vegetable-related foodborne illness.

Check your steps at FoodSafety.gov. Also see the chapter on Food Safety.

Some foods are more frequently associated with foodborne illness. With these foods, it is especially important to:

- **CLEAN:** Wash hands and food preparation surfaces often. And wash fresh fruits and vegetables carefully.
- **SEPARATE:** Don't cross-contaminate! When handling raw meat, poultry, seafood, and eggs, keep these foods and their juices away from ready-to-eat foods.
- **COOK:** Cook to proper temperature. See the [Minimum Cooking Temperatures chart](#) for details on cooking meats, poultry, eggs, leftovers, and casseroles.
- **CHILL:** At room temperature, bacteria in food can double every 20 min.

The more bacteria there are, the greater the chance you could become sick. So, refrigerate foods quickly because cold temperatures keep most harmful bacteria from multiplying.

Regardless of its source, it is recommended that “ready-to-eat” value-added fresh produce be *washed* prior to consumption, and then refrigerated in order to maintain food safety. Washing is recommended despite the label statement that the product is washed and ready-to-eat.

Cross-contamination from other foods, such as meats, should be avoided, pull dates should be adhered to, and assembly/preparation areas should be sanitary. Of course personal hygiene is crucial to food safety.

Hydrogen peroxide is a generally recognized as safe (*GRAS*) substance that has also been used as a bleaching agent (as in milk used for cheese), and as an antimicrobial agent in foods. Some antimicrobials are effective due to their low pH, yet are not usable due to the unacceptable flavor that they impart. Other substances having antimicrobial properties include essential oils from citrus, coriander, mint, parsley, and vanillin juice peels.

Conclusion

Plant tissue is composed primarily of parenchyma tissue. The structure and composition of a fresh fruit or vegetable changes as the cell is destroyed. As fruits and vegetables typically contain a very large percentage of water, the maintenance of turgor pressure is an important factor in determining plant material quality.

The desirable pigments and flavor compounds contained in fruits and vegetables may undergo unacceptable changes upon preparation and cooking. Discoloration of some cut vegetables or fruits is known as EOB, which must be controlled. Improper storage or cooking can result in quality losses.

The nutritive value of vitamins, pro-vitamins (carotene) minerals, fiber, and other compounds contained in fruits and vegetables are extremely important to the diet, and there are medicinal benefits of fruits and vegetables. Many are low in fat content. Vegetarian food choices may be met with consumption of a variety of fruits and vegetables. “Vary your veggies” and “focus on fruits” is the USDA advice in selecting vegetables and fruits as part of a healthy diet.

Biotechnology provides the consumer with greater economy and convenience. Coupled with an understanding of the role of phytochemicals in disease prevention, vegetables and fruits may provide a greater nutrient contribution to the human diet. Irradiation is utilized as a means of ensuring food safety. Items of high nutritional value that were once unfamiliar and not used, as well as new items from around the world are now available on grocery shelves.

Notes

CULINARY ALERT!

Glossary

Allium Flavor compounds in the genus *Allium* that contain sulfur compounds and offer phytochemical value.

Anthocyanin Red-blue pigmented vegetables of the Flavone family.

Anthoxanthin Whitish pigmented fruits and vegetables of the Flavone group of chemicals.

Biotechnology Biogenetic engineering of animals, microorganisms, and plants to alter or create products that have increased resistance to pests, improved nutritive value, and shelf life.

Brassica Flavor compound of *Brassica* genus including cruciferous vegetables with sulfur compounds.

Carotenoid The group of red-orange pigmented fruits and vegetables; some are precursors of vitamin A and also have antioxidant value.

Cellulose Glucose polymer joined by β -1,4 glycosidic linkages; cannot be digested by human enzymes, thus it provides insoluble dietary fiber.

Cell sap Found in the plant vacuole; contains water-soluble components such as sugars, salts, and some color and flavor compounds.

Chlorophyll The green pigment of fruits and vegetables.

Cytoplasm Plant cell contents inside the cell membrane, but outside the nucleus.

Diffusion Movement of solute across a permeable membrane from an area of greater concentration to lesser concentration in heated products that do not have an intact cell membrane.

Enzymatic oxidative browning Browning of cut or bruised fruits and vegetables due to the presence of phenolic compounds, enzymes, and oxygen.

Fresh Alive and respiring as evidenced by metabolic and biochemical activities.

Fruit The mature ovaries of plants with their seeds.

Hemicellulose The indigestible fiber in cell walls that provides bulk in the diet; may be soluble, but primarily insoluble.

Lignin The noncarbohydrate component of fiber of plant tissue that is insoluble and excreted from the body. It provides the undesirable woody texture of mature plants.

Middle lamella The cementing material between adjacent plant cells, containing pectic substances, magnesium, calcium, and water.

Nutraceuticals The name given to a proposed new regulatory category of food components that may be considered a food or part of a food and may supply medical or health benefits including the treatment or prevention of disease. A term not recognized by the FDA.

Osmosis The movement of water across semi-permeable membranes from an area of greater concentration to lesser concentration in products with an intact cell membrane.

Parenchyma tissue Majority of plant cells containing the cytoplasm and nucleus.

Pectic substances The intercellular “cement” between cell walls; the gel-forming polysaccharide of plant tissue.

Phytochemicals Plant chemicals; natural compounds other than nutrients in fresh plant material that help in disease prevention. They protect against oxidative cell damage and may facilitate carcinogen excretion from the body to reduce the risk of cancer.

Turgor pressure Pressure exerted by water-filled vacuoles on the cytoplasm and the partially elastic cell wall.

Vacuole Cavity filled with cell sap and air.

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