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Carbohydrates and Fiber

Carbohydrates are the most abundant of the compounds in living plants, other than water, and serve as a principal repository of photosynthetic energy. They are in above-ground parts (stem, leaves, flowers, fruits, and seeds) and belowground parts (roots and tubers); constitute about 50-80% of the dry matter in leaves, fruits, and seeds; and generally furnish 40% or more of the metabolizable energy in the diets of most primate species, including humans and animals .

CARBOHYDRATE CLASSIFICATION, CHARACTERISTICS, DIGESTION, AND METABOLISM

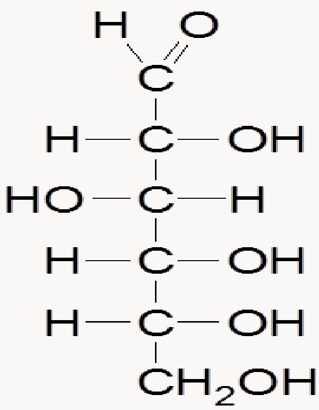
Carbohydrates are classified according to size or unite of glucose as monosaccharides, disaccharides, oligosaccharides, or polysaccharides.

Monosaccharides (single glycose unit):	**Oligosaccharide to 10 glycose units):**	**Polysaccharides (> 10 glycose units):**
Trioses ($C_3H_6O_3$) Glyceraldehyde & Dihydroxyacetone Tetrose ($C_4H_8O_4$) Erythrose Pentoses ($C_5H_{10}O_5$) Ribose, Arabinose, Xylose, and Xylulose Hexoses ($C_6H_{12}O_6$) Glucose, Galactose, Mannose, and Fructose	Disaccharides ($C_{12}H_{22}O_{11}$) Sucrose, Maltose, Cellobiose, and Lactose Trisaccharides ($C_{18}H_{32}O_{16}$) Raffinose Tetrasaccharides ($C_{24}H_{42}O_{21}$) Stachyose Pentasaccharides ($C_{30}H_{52}O_{26}$) Verbascose	Homoglycan (.single glycose. units) Pentosans ($(C_5H_8O_4)_n$ Arabans, and Xylans Hexosans ($(C_6H_{10}O_5)_n$ Glucans, Starch , Dextrins , Glycogen and Cellulose.

Monosaccharides

Monosaccharides, often called simple sugars, are single carbohydrate units that contain three to seven carbon atoms. The six-carbon monosaccharides (hexoses) that are particularly important in animal nutrition are glucose, fructose, and galactose.

Glucose is a moderately sweet simple sugar present in honey, ripe fruits, and some vegetables in free form and combined with fructose, forms the disaccharide sucrose. It is the chief end-product of starch digestion in rats, pigs, and humans. It is absorbed through the intestinal wall, is transported via the portal vein to the liver, circulates in the blood, and is the primary carbohydrate used by the body's cells for energy. Amounts in excess of immediate need can be stored as glycogen or fat. Although glucose can be used for energy by all cells, it is essential for erythrocytes and brain cells. If unavailable in the diet or glycogen stores, glucose can be produced in small amounts from non-carbohydrate sources (gluconeogenesis). Thus, glucose—and carbohydrates in general— in the short term is not considered a dietary essential, but there are energetic costs associated with gluconeogenesis, and it is likely that minimum dietary concentrations of carbohydrates probably must be present for optimal health and metabolic efficiency. Acquisition of minimal amounts of carbohydrate does not pose a practical problem, because diet formulations designed to meet essential protein (amino acid), fatty acid, mineral, and vitamin requirements have adequate space for any conceivable carbohydrate need.



Fructose is a very sweet simple sugar present in honey, ripe fruits, and some vegetables in free form and combined with glucose in sucrose. The enzymes in the mucosal cell brush border appear to adapt to increased intakes of sucrose or fructose, and fructose transport into plasma is accelerated by high intakes of fructose or sucrose in the rat and baboon . Limited amounts of fructose may be used directly for energy or converted into glucose by intestinal mucosal cells. Most of the fructose that reaches the liver via the portal vein is converted to glucose, lipid, or lactate.

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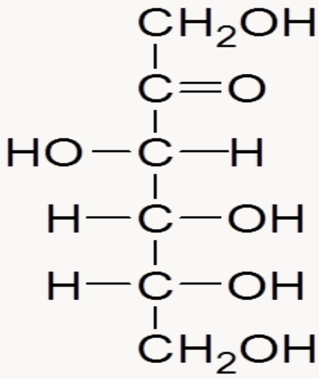
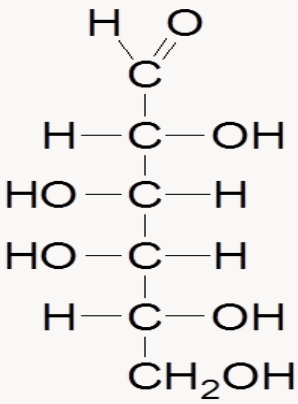


Galactose: is a simple sugar that is not very sweet and is seldom present free in foods. It is usually bound with glucose in the disaccharide lactose, which is found in mammalian milks. Digestion of lactose releases glucose and galactose; after absorption, galactose is converted to glucose in the liver, although the kidney and erythrocyte may be involved in galactose metabolism to a minor extent.



Disaccharides

A disaccharide consists of two monosaccharide units linked together, such as the disaccharide sucrose which is a plant energy reserve. Monosaccharides and disaccharides are known collectively as soluble sugars.

Sucrose (glucose + fructose) is present in high concentrations in sugar cane and sugar beets and in much lower concentrations in fruits, vegetables, seeds, and nuts . Adults have no problem in digesting sucrose, but very young baby animals(such as baby pig) show little ability to use dietary sucrose or fructose unless gradually adapted to them .

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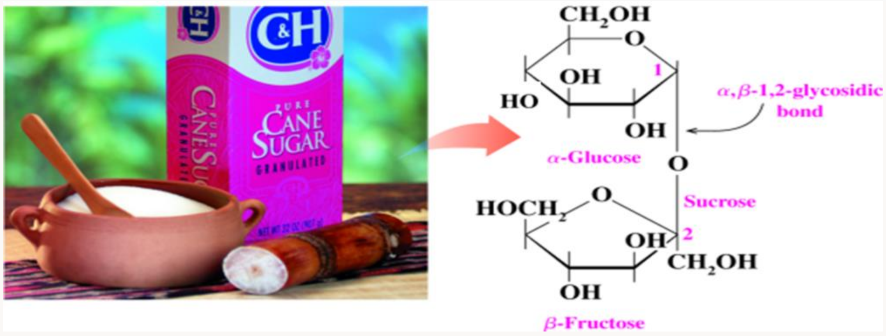
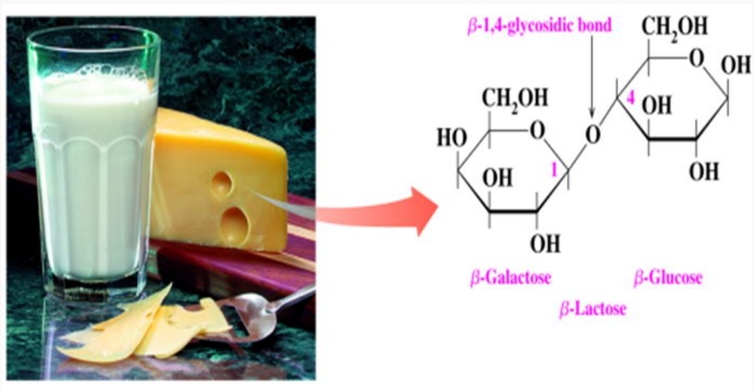


Sucrose

Lactose (glucose + galactose) is present in most mammalian milks. Some adult humans exhibit lactose intolerance associated with limited intestinal lactase activity; intolerance to lactose also has been reported in captive macaques and poultry birds.



Maltose (glucose + glucose) is seldom present free in foods but is an intermediate formed during the digestion of starch to glucose.

Oligosaccharides

An oligosaccharide is a polymer of three or more monosaccharide units. Some are intermediates in the synthesis or degradation of polysaccharides. Oligosaccharides include **raffinose** (a trisaccharide: fructose + glucose + galactose), **stachyose** (a tetrasaccharide: fructose + glucose + two galactose molecules), and **verbascose** (a pentasaccharide: fructose + glucose + three galactose molecules) . Raffinose and stachyose have been found, and their concentrations determined, in some grains, leguminous seeds, nuts, and vegetables.

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Polysaccharides

Polysaccharides are large, and often complex, polymers of multiple monosaccharide units. They can be divided into two types, starch and starch-like compounds, which are the only polysaccharides directly digestible by mammals, and non-starch polysaccharides. Non-starch-polysaccharides can be further divided into two sub-categories, insoluble non-starch polysaccharides, also referred to as insoluble fiber, and soluble non-starch polysaccharides, or soluble fiber

STARCH AND STARCHLIKE POLYSACCHARIDES

Starch, a polymer of glucose, is a plant energy reserve and occurs in granules that consists of amylose and amylopectin in various proportions. Amylose is primarily a straight-chain polymer of glucose units linked by α-1→4 glycosidic bonds. Amylopectin is a branched-chain polymer of glucose units linked by α-1→4 and α-1→6 glycosidic bonds. Starch solubility ranges from soluble to highly insoluble but tends to form a gel in water unless physical or enzymatic treatment is applied to promote dissolution . Starch digestion by endogenous mammalian enzymes involves salivary and pancreatic α-amylases and yields maltose, maltotriose, some glucose, and limit dextrin (three to five α-1,4-glucose units and one α-1,6-glucose unit). Further digestion to glucose is accomplished principally by maltase in the intestinal brush border. Resistant starch escaping enzymatic digestion or foregut fermentation may undergo microbial fermentation in the hindgut.When high-starch diets are fed, excessively rapid fermentation may lead to digestive upsets, characterized by signs of abdominal discomfort and poor stool quality. This is particularly serious when high-starch, low-fiber foods are consumed by foregut fermenting primates, and may result in death.

Starch
- Amylose (20%)
- Amylopectin (80%)

(starch that stores glucose in plants suchas rice, potatoes, beans, and wheat - energy storage).

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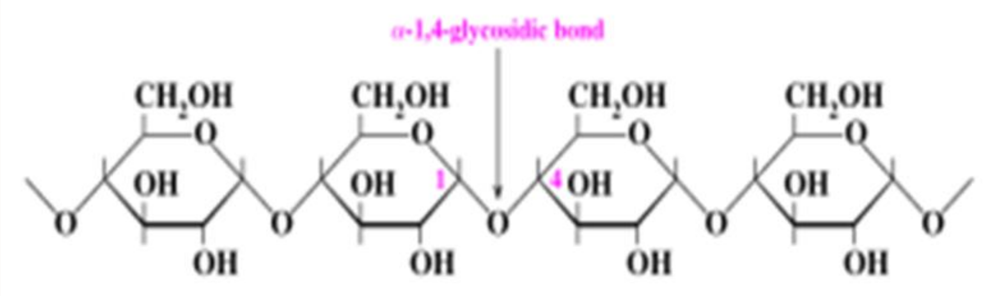
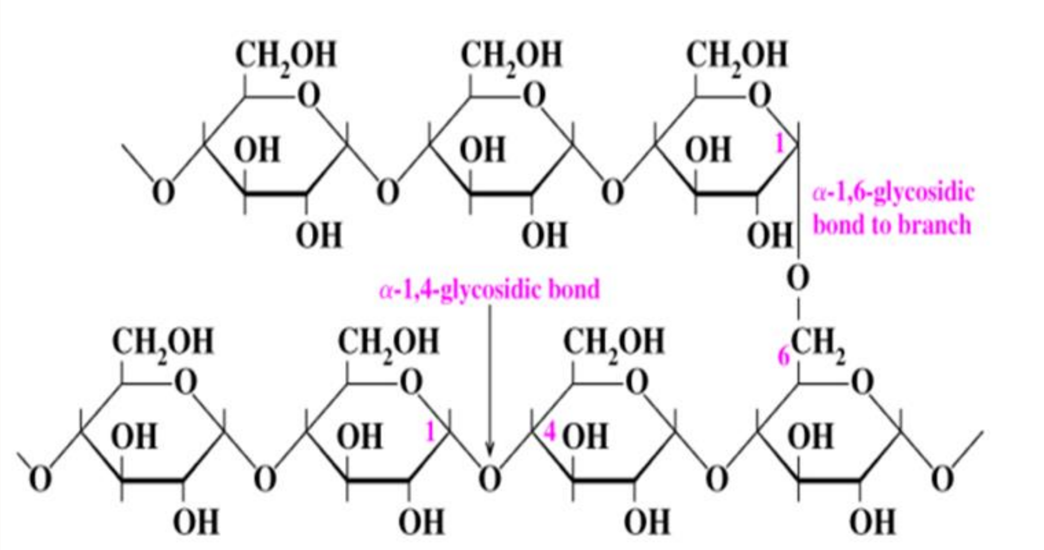


Amylose



Amylopectin

Glycogen is an animal energy reserve consisting only of amylopectin and is of little quantitative significance in the diets of most nonhuman primates.

Dextrins are polymers of glucose and are intermediates in the digestion of amylopectin (principally from starch).

Digestive process

Amylose, Amylopectin (starch) converted to Dextrins (6-8 glucose units) by H^+ or α-amylase (enzyme in saliva) then converted to Maltose (2 glucose units by H^+ or α-amylase (enzyme in pancreas) finally product is Many α-D-glucose units by H^+ or α-maltase (enzyme).

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NON-STARCH POLYSACCHARIDES

Insoluble non-starch polysaccharides do not dissolve in water, nor do they generally swell in water to form a gel. Cellulose and hemicelluloses are structural polysaccharides making up the bulk of plant cell wall and also are referred to as insoluble fiber. They are commonly included in measures of fiber, along with non-carbohydrate components of cell wall, such as the highly complex phenylpropanoid lignin and the fatty substances cutin, suberin, and waxes. Other non-carbohydrate substances variously associated with cell wall (but not usually a part of fiber) are silica, calcium carbonate, tannins, resins, volatile oils, and crystalline pigments.

Cellulose is a polymer of 1,000 or more glucose molecules bound together by β-1→4 linkages that cannot be broken (digested) by endogenous mammalian enzymes. Symbiotic gastrointestinal anaerobes can release the energy of cellulose through microbial fermentation and the production of volatile fatty acids, although digestion may not be complete. The principal volatile fatty acids are acetic, propionic, and butyric acids (in descending order of usual abundance) plus small and variable amounts of isobutyric, valeric, and isovaleric acids. Much of the butyric acid (and some acetic acid) can be used directly for energy by inteslnal cells. The other volatile fatty acids are absorbed and enter metabolic pathways. Wheat bran is an example of a food source of cellulose.

Hemicelluloses are a heterogeneous group of single and mixed polymers of arabinose, xylose, mannose, glucose, fucose, galactose, and glucuronic acid closely associated with cellulose and lignin. Examples are xyloglucans, xylans, glucomannans, arabinoxylans, and glucuronoxylans. Most hemicelluloses are water insoluble, but a few will form a viscous or gel-like solution. Like cellulose, hemicelluloses cannot be digested by endogenous mammalian enzymes, although they can be partially hydrolyzed in the acid stomach. Anaerobic fermentation is required for effective use of the energy that hemicelluloses contain, and the products of fermentation are essentially the same as those of cellulose. Humans and chimpanzees ferment hemicelluloses somewhat more completely than they do cellulose.

Soluble non-starch polysaccharides do not dissolve in water completely but swell to form a gel or a gummy solution. Nevertheless, they are referred to as soluble fiber. They are nonstructural polysaccharides, some of which serve as plant energy reserves, but they are not as digestible as starch, although fermented quite completely by ruminal and intestinal bacteria.

Included among the non-starch plant energy reserves are fructans, mannans, and galactans. **Fructans** (also known as fructosans, and including inulin) are polymers of fructose that are stored in grasses and composites , as well as in parts of some food crops . Fructans are broken down in an acid environment, so passage through the acid stomach may result in release of some fructose monomers that can be absorbed in the small intestine. **Mannans** are polymers of mannose found in sea weeds, algae, nuts, and seeds. **Galactans** are polymers of galactose found in sea weeds, algae, and with pectin in fruit pulps.

Pectic substances are not plant energy reserves but are associated with the plant cell wall. Despite this association, their relative solubility results in their inclusion among the soluble non-starch polysaccharides along with soluble β-glucans and other gums. That cannot be digested by endogenous mammalian enzymes. Like cellulose and hemicelluloses, however, they can be degraded by fermentation, and microbial degradation of pectic substances is often quite complete)

A classification of common dietary carbohydrates and associated digestive enzymes or digestive processes is shown in Table -1.

TABLE -1 Common Dietary Carbohydrates and Their Digestion

Carbohydrate	Simple-Sugar Components	Digestion	Digestive Products
Maltose	Glucose	Maltase[a]	Glucose
Sucrose	Glucose, fructose	Sucrase[a]	Glucose, fructose
Lactose	Glucose, galactose	Lactase[b]	Glucose, galactase
Starch	Glucose	Amylases[a]	Glucose
Fructans	Fructose	Gastric acid[a]	Fructose
Galactans	Galactose	Fermentative	Volatile fatty acids
Mannans	Mannose	Fermentative	Volatile fatty acids

Pectins	Arabinose, galactose	Fermentative	Volatile fatty acids
Hemicelluloses	Arabinose, xylose, mannose, galactose, glucuronic acids	Fermentative	Volatile fatty acids
Cellulose	Glucose	Fermentative	Volatile fatty acids

[a]In primates with pregastric digestive compartments, digestion is primarily fermentative, yielding volatile fatty acids. Carbohydrates escaping digestion by endogenous enzymes in primates without pregastric digestive compartments may be digested fermentatively in the hindgut.
[b]Lactase activity declines after weaning in some species, and lactose may be digested fermentatively.