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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.**

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.

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.

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 .

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.

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, 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.

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).

Carbohydrate metabolism :

Carbohydrate are the major components in plant tissues . they comprise up to 70% or more of the dry matter of forages . higher concentrations (up to 85%) may be found in some seeds , especially cereal grains . carbohydrates , containing mainly of glucose and glycogen , make up less than 1% of the weight of an animals .

Functions :

In animal nutrition carbohydrates serve primarily as a source of energy for normal life processes .

Metabolism

Preparation for absorption :

Digestion in the small intestine : only monosaccharides can be absorbed from the GIT except in newborn animals capable of absorbing larger molecules . thus , for absorption to occur , poly , tri and disaccharides must be hydrolyzed by digestive enzymes elaborated by the host or by microflora inhabiting the GIT of the host .

Microflora of the rumen of ruminants and the cecum and colon of some nonruminants , such as the horse and rabbit , produce cellulase , which is capable of hydrolyzing the glucose -4-beta-glucoside linkage of cellulose . consequently , these species can utilize large quantities of cellulose . other nonruminants , including humans and swine , also utilize cellulose by anaerobic fermentation in large intestine by virtue of the production of cellulase by some of the microorganisms residing in the lower intestinal tract but not by mammalian cells .35

Microbial fermentation of cellulose and other plant fibers :

In ruminants and other species with large microbial populations in the GIT . anaerobic fermentation of carbohydrates results in the production of large quantities of volatile fatty acids (VFA) , mainly acetic , propionic and butyric acids , and provides a large proportion of the total energy supply .even in pigs whose ability to utilize cellulose is less than that of ruminants , some of the energy required for maintenance can be provided by VFA produced by microbial action on fiber in the large intestine .

Energetics of glucose catabolism :

The total energy released in the conversion of glucose to CO_2 and H_2O is 673 Kcal/mole . this can be illustrated as follows :

$C_6H_{12}O_6 \rightarrow 6CO_2 + 6H_2O + 673$ Kcal

The molecular weight of glucose is 180.2 , thus the gross energy value of glucose is 673 / 180.2 = 3.74 Kcal / g . in the oxidation of metabolites via the citric acid cycle , the 57 Kcal /mole of water formed (total of 6 × 57 = 342kcal) represents heat production and is wasted energy , equivalent to the amount of energy that must be ingested and absorbed for the animal to stay in energy balance .

Catabolism of 1 mole of glucose by the glycolytic pathway is associated with the following amounts of adenosine triphosphate (ATP) trapped at each stage of oxidation to CO_2 and H_2O "

Glycolytic pathways (8 mole of ATP)

2 pyruvate to 2 acetyl CoA (6 mole of ATP)

2 acetate to 2 CO_2 and H_2O (24 mole of ATP)

Total (38 mole of ATP) 36

ATP serves as a major form of high-energy phosphate bonds . one mole of ATP has a value of about 8 Kcal / mole . that is ..

ATP → ADP + 8 Kcal / mole .

Carbohydrate digestion in ruminants :

Carbohydrate digestion in ruminants is largely the result of microbial fermentation in the rumen . fermentation is anaerobic respiration . dietary carbohydrates are fermented , mainly by rumen bacteria , and the absorbed energy sources for the animal are the bacterial waste products , the VFAs . the VFAs were originally termed steam-volatile fatty acids , because they are volatilized from solution by the action of passing steam through the solution . steam distillation of volatile compounds was a common technique in the early days of biochemistry . they are also known as short chain fatty acids (SCFA) . As a generalization , ruminants meet their protein needs by digesting rumen microbes ,while they meet their energy needs by absorbing the waste products (VFAs) of rumen bacterial fermentation .

Rumen fermentation of carbohydrates :

Bacteria , protozoa and fungi are the three types of rumen microorganisms (RMO) . they all have roles in carbohydrate digestion , although bacteria are the most important . bacteria secrete enzymes that split the bonds linking sugars together in oligosaccharides and polysaccharides , resulting in the release of free sugars .these are taken up immediately by the bacteria , and metabolized as energy sources . because the rumen is primarily anaerobic , the bacteria cannot oxidize sugars completely to carbon dioxide and water (luckily for the ruminant) ,they excrete carbon fragments in the form of VFAs , carbon dioxide and methane (CH_4) .small amounts of oxygen may enter the rumen , as air swallowed during 37 feeding . although oxygen is toxic to obligate anaerobic bacteria , it is quickly utilized by facultative anaerobes .

Cellulose fermentation :

Bacteria that produce cellulase enzyme are called cellulolytic bacteria . they attach to fiber particles and the cell walls of fibrous plant material consumed by the animal . there is little or no free cellulase in the rumen contents . cellulolytic bacteria invade the plant cells and tend to digest them from inside .

Starch fermentation :

Starch is a major dietary constituents of concentrated fed-ruminants , such as dairy and feedlot cattle . starch-digesting or amylolytic rumen bacteria . the rate of degradation of starch depends upon its source and feed processing method .

End-products of rumen fermentation :

The main end products of rumen fermentation are microbial cell mass , gases , heat (the heat of fermentation) and the VFAs. The main gases produced during rumen fermentation are CO_2 , CH_4 and small amounts of hydrogen and hydrogen sulfide . rumen gas is typically about 65% CO_2 and 25% CH_4 , so the methane in the rumen is a hydrogen sink . the proportions of the three major VFAs , acetate (C2) ,propionate (C3) and butyrate (C4) , produced in the rumen are influenced by diet . cellulolytic bacteria tend to produce more C2 so acetate makes up 75% or more of total VFAs with a roughages based diet . with high concentrate diets propionate is the major VFAs .