CARBOHYDRATES

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Contents

Summary

The name carbohydrate is given to a large group of natural compounds occurring in living organisms and carbohydrates are constituents of majority of foods. The name is based on the observation in early history of organic chemistry. It was found by chemists that a large number of natural substances such as sugars, starch and cellulose, all have empirical formulae of type $(C_x (H_2O)_y$, and can be regarded as “hydrates of carbon”. Although, later it became clear that these compounds are not “hydrates” the old name was retained. Chemically carbohydrates are *polyhydroxi aliphatic compounds bearing also carbonyl or carboxyl group.*

These compounds constitute more than one half of the organic matter upon the Earth. Carbohydrates are the main constituents of plants while the animal world contains rather

limited amounts of them. The most abundant carbohydrate is the cellulose, the principal structural component of plants. The major carbohydrate consumed by humans is the starch, providing energy for human body.

Carbohydrates which cannot be broken down by hydrolysis into smallers ones are termed *monosaccharides.* When two or three molecules of monosaccaride are joined together they form disaccharides or trisaccharides, respectively. Such combined sugars containing from two to ten monosaccharide residues are the *oligosaccharides.* By definition, any carbohydrate polymer containing more than ten monosaccharide residues is considered a *polysaccharide.* From chemical point of view, monosaccharides are classified according to carbon atoms number in the molecule to trioses, tetroses, pentoses, hexoses etc.

Depending on the position of the carboxyl group in the molecule, monosaccharides may be polyhydroxialdehides (aldoses) or polyhydroxiketones (ketoses). Due to stereoisomer forms, monosaccharides are divided to D- and L-monosaccharides. Different formulas are used in literature to present the structure of most commonly occurrig monosaccharides, the hexoses: the open chain formula, the flat ring formula (Hawthorne formula), and the chair- or boat ring formula.

Carbohydrates in foods: Carbohydrates are present in all grains, vegetables, fruits and other plant parts eaten by humans. Starch and sucrose (commercial crystalline sugar) are the main energy sources for man. Starch is the main constituent of cereals, flour, and cereal based products. Sucrose is isolated from sugar beet and sugarcane and used in production of many sweet goods. Ripe fruits contain sucrose, glucose and fructose. In addition to the consumption of carbohydrates for the caloric needs, humans and animals alike appreciate the sweetness of sugars, such as sucrose and fructose. Their content and ratio is depending on fruit variety. The tendency toward greater consumption of sweet sugars in place of starchy foods may contribute to physiological changes, such as increase in dental caries and obesity.   Some of polysaccharides, mainly cell walls (fibers) are nondigestible. However, due to their beneficial effect on healthy intestinal activity, consumption of foods of plant origin containing such polysaccharides is recommanded by nutritionists. A general name used for such components is: *dietary fiber*. Lactose, a disaccharide of milk, plays an important role in energy supply of babies and young children.

A lot of natural sugar derivatives, occurring mainly in foods of plant origin, are known and many of them are involved in metabolic reactions of living organism. Sugar derivatives are used also in food production. E.g. sugar alcohols are applied as alternative sweeteners, some sugar derivatives are emulsifiers and gel-forming agents.

1. Introduction

The term carbohydrate expresses the early determined elementar composition of these compounds. It was found by chemists that a large number of natural substances such as sugars, starch and cellulose, all have empirical formulae of type $C_x\,(H_2O)_y$, and can be regarded as „hydrates of carbon”. As chemical methods evolved, this empirical formula was replaced by a more descriptive graphic formulation that gave a clear visualization of spacial or steric structure. Although, it became clear that these compounds are not „hydrates" the old name was retained. Chemically carbohydrates are *polyhydroxi aliphatic compound bearing also carbonyl or carboxyl group.*

These compounds are the main organic constituents in living organisms of the biosphere of the Earth. Carbohydrates (primarily cellulose) are the principal structural components of trees and other plants while the animal world contains rather limited amounts of them. The major carbohydrate consumed by humans is the starch, providing about 70% of energy required for human organism.

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In addition to the consumption of carbohydrates for the caloric needs, humans and animals alike appreciate the sweetness of sugars. The tendency toward greater consumption of sweet sugars in place of starchy foods may contribute to physiological changes, such as increase in dental caries and obesity. Some of polysaccharides, mainly cell walls (fibers) are nondigestible. However, due to their beneficial effect on healthy intestinal activity, consumption of foods of plant origin containing such polysaccharides is recommanded by nutritionists. A general name used for such components is: *dietary fiber*. Lactose, a disaccharide of milk, plays an important role in energy supply of babies and young children.

A lot of sugar derivatives are known and many of them are used in food production. E.g. sugar alcohols are applied as alternative sweeteners, some sugar derivatives are emulsifiers and gel-forming agents. Starch and some starch derivatives are also important additives used in food production. In the framework of this contribution the most common carbohydrates will be treated concentrating on their occurrence, role in human nutrition. Only some basic chemistry of carbohydrates is uncluded in this article. For more detailed information about chemistry of these compounds the readers are referred to literature given at the end of this contribution.

2. Classification

Carbohydrates can be classified into three groups based on the number of sugar units they contain:

Monosaccharides
Oligosaccharides, and
Polysaccharides

Monosaccharides are simple sugars that cannot be hydrolysed into smaller units under reasonable mild conditions. Based on type of carbonyl group, monosaccharides may be divided into two groups: *aldoses* and *ketoses*. Depending on the number of carbon atoms in the molecule monosaccharides are termed trioses (C_3), tetroses (C_4), pentoses

(C_5), hexoses (C_6), heptoses (C_7) etc. The naturally occuring monosaccharides contain 3 to 9 carbon atoms. Oligosaccharides are hydrolyzable polymers of monosaccharides that contain from two to ten molecules of simple sugars. The disaccharides, which contain two monosaccharide units, are the most abundant; trisaccharides also occur in the nature. Oligosaccharides with more than three monosaccharide units are usually found bound as side chains of glycoproteins.

Polysaccharides are polymers, frequently insoluble, consisting of hundreds or thousands of monosaccharide units. If the polymer is made up from a single monosaccharide, the polysaccharide is called *homopolysaccharide.* If two or more different monosaccharides are found in the polysaccharide, it is called a *heteropolysaccharide.*

3. Chemistry of Carbohydrates

3.1. Monosaccharides

The simplest monosaccharides are the glyceraldehyde and dihydroxy acetone (Fig.1.). In the nature and also in the foods, the monosaccharides of primary importance are hexoses and pentoses. The most known hexose is the ***glucose.*** Glucose molecule, and except the dihydroxy acetone, all monosaccharides molecules have stereoisomers and among them two enantiomers which are designated by capital letters D- and L. (For details concerning molecular structure of monosaccharides the reader is referred to literature listed at the end of this article).

$$\mathbf{HO_2HC\text{-}CHOH\text{-}CHO} \qquad\qquad \mathbf{HO_2HC\text{-}CO\text{-}CH_2OH}$$

Figure 1: Glyceraldehyde and dihidroxy acetone

In older literature monosaccharides were presented in “open chain” formula (Figure2, left) proposed by Fisher. Later it was found that the glucose molecule has a cyclic form and two additional isomers designated by Greek letters alpha- and beta. The cyclic formula proposed by Haworth is shown also in Fig.2 (middle). Finally it was found that the cyclic structure is not planar but has a “chair” (or “boat”) form as seen in Fig.2 (right).

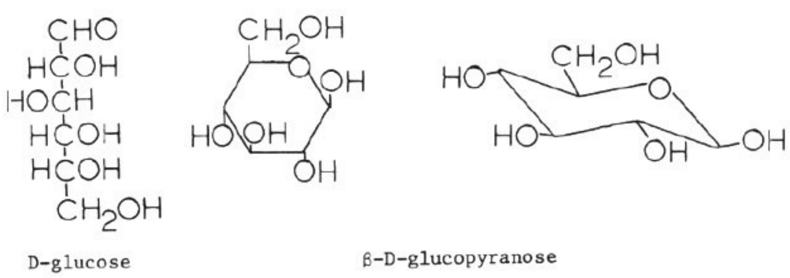

Figure 2: Different presentations of glucose molecule; a-open chain, b-planar ring, c-chair form

Among other monosaccharides the ***fructose,*** a ketohexose (Fig.3.) should be mentioned. The name of this compound is derived from roman name of fruit because fructose is a characteristic sugar of fruits. ***Galactose*** is a constituent of disaccharide lactose, a sugar of milk. The pentose ***D-ribose*** is constituent of nucleic acids.

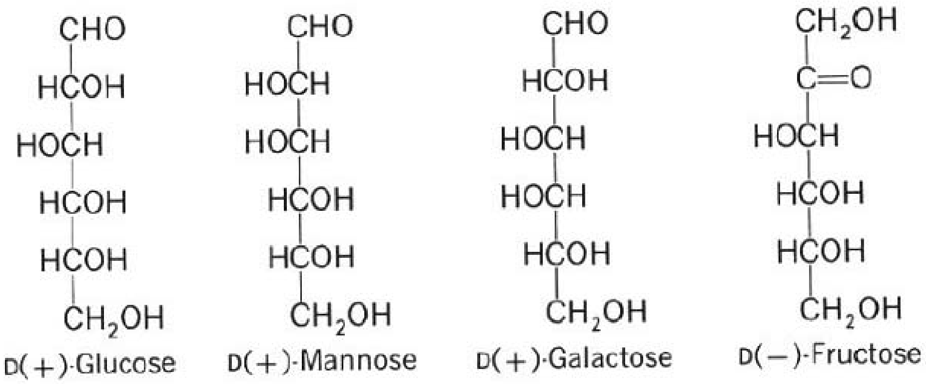

Figure 3: D-glucose, D-mannose, D-galactose and D-fructose

A lot of monosaccharide derivatives occur in the nature and some are synthetized by chemists. Uronic acids (such as glucuronic- and galacturonic acid) are building units of some polysaccharides. Other derivatives (e.g. glucose phosphates) are present in small quantities in plant and animal tissues. Gluconic acid is a known food additive produced on commercial scale.

3.2. Oligosaccharides

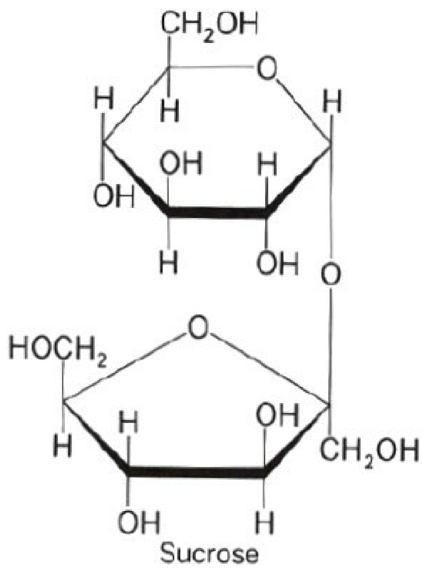

Figure 4: Sucrose

Disaccharides, the most known group of oligosaccharides, consist of two monosaccharide units condensed with the concominant loss of water. Common disaccharides in foods are ***sucrose*** (cane or beet sugar) (Fig 4), ***maltose*** and ***lactose*** (milk sugar, Fig 5). Disaccharides may be hydrolysed by acids or enzymes and so from sucrose D-glucose and D-fructose can be obtained. The products of hydrolysis of lactose are the D-glucose and D-galactose. Maltose consists from two molecules of D-glucose.

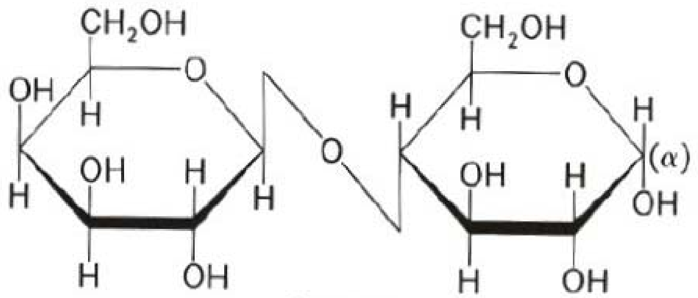

Figure 5: Lactose

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Biographical Sketches

Jiří Davídek, PhD., Dr Sc., is a Professor of Food Science in the Faculty of Food and Biochemical

Technology, and is a member of the Department of Food Chemistry and Analysis, Institute of Chemical Technology, Prague, Czech Republic.

Professor Davídek received his M. Sc. degree from the Institute of Chemical Technology, Faculty of Food and Biochemical Technology in 1954. He obtained his Ph.D. in 1969 from the same Institute under the direction of Prof. Dr. G. Janíček. After doing postdoctoral work with Dr. J. Fragner at the Research Institute of Food Industry in Prague and with Dr. A. W. Khan at National Research Council, Division of Biosciences in Ottawa, Canada He was appointed Associate Professor of Food Chemistry and Analysis at the Faculty of Food and Biochemical Technology, Institute of Chemical Technology, Prague in 1960 and became a full Professor there in 1970.

Prof. Jiří Davídek is a member of the Czech Chemical Society and the chairman of the Division of Food and Agricultural Chemistry. He is a national representative in Food Chemistry Division, Federation of European Chemical Societies (FECS) and is member of Czech Biochemical Society, the American Institute of Food Technologists and numerous other scientific societies. He is also a member of the editorial board of the Czech Journal of Food Sciences, German European Research and Technology and Chinese Biomedical and Environmental Sciences. He has served as the head of the Department of Food Chemistry and Analysis, dean of the Faculty of Food and Biochemical Technology in Prague, and the vice chairman of the Czechoslovak Academy of Agriculture. In 1972 he received the State Price for Research, and in 1982 he was awarded both the Gold Medal from the Czechoslovak Academy of Agriculture and Silver Medal of Professor Jaroslav Heyrovsky from the Czechoslovak Academy of Science.

Prof. Davídek has published over 330 papers and is author of 16 books published variously in Czech, English, German and Polish. He has also delivered more than 350 lectures at scientific conferences and symposiums. He often works as a chairman at the International meetings organised by Food Chemistry Division of FECS (Euro Food, Chemical Reactions in Foods, etc.). His research interests focus on food quality, food analysis, on Maillard reactions, formation of sensory active compounds, food additives and natural toxic compounds.

Radomir Lasztity D.Sc, Professor of the Department of Biochemistry and Food Technology at Budapest University of Technology and Economics, was born in 1929 in Deszk, Hungary. Dr Lasztity received his M.Sc. degree in Chemical Engineering in 1951 and his D.Sc. degree in Chemical Science in 1968. He is honorary president of International Association for Cereal Science and Technology (ICC) and deputy technical director. He was acting chairman of the Codex Committee on Methods of Analysis and Sampling of the FAO/WHO Food Standard Program in the period 1975 – 1988. Dr Lasztity is a member of the Food Chemistry Division of the Federation of European Chemical Societies., and a member of the editorial boards of several international scientific journals. Among other awards he has received the Bailey and Schweitzer Medal of the ICC, the State Prize of the Hungarian Republic, and the Golden Medal of Czech Academy of Sciences. Dr Lasztity's main research activities are chemistry and biochemistry of food proteins, food analysis and food quality control. He has published more than 800 articles in Hungarian and overseas journals. He is the author/editor of more than twenty books and textbooks [*Chemistry of cereal proteins (1984, second ed. 1996), Amino Acid Composition and Biological Value of Cereal Proteins (1985), Cereal Chemistry (1999), Use of Yeast Biomass in Food Production (1991), Gluten Proteins (1987)*].