Food Carbohydrate Chemistry

Ronald E. Wrolstad

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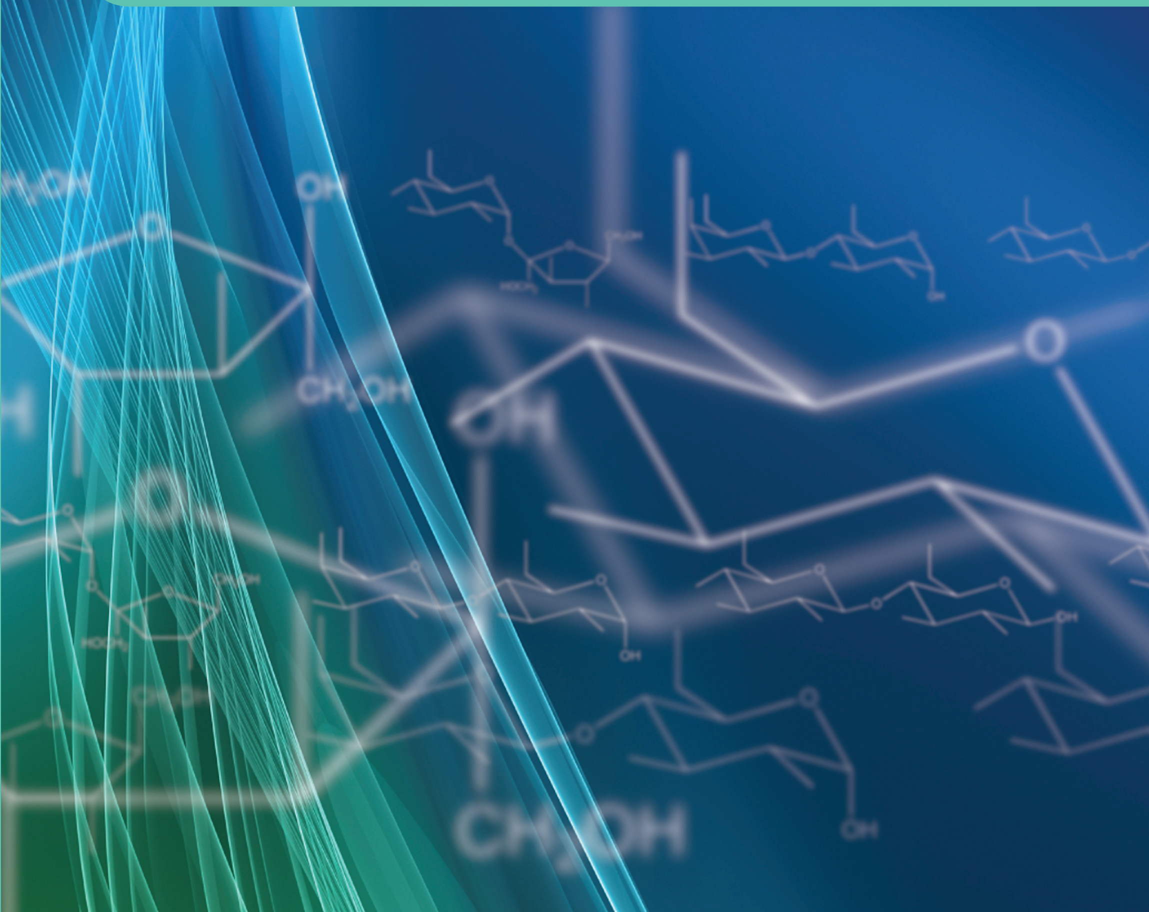

Food Carbohydrate Chemistry

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Dedication

This book is dedicated to two special mentors, one being my Major Professor at the University of California, Davis, Dr. Walter G. Jennings. His concern for students and his enthusiasm for research and teaching continue to inspire. The second is the late Robert S. Shallenberger with whom I was fortunate to work while on sabbatical leave at Cornell University in 1979–1980. His influence on this book should be evident on nearly every page. I would also like to dedicate the book to the many undergraduate and graduate students, who through their suggestions, understanding, and misunderstanding helped me to revise, discard, and improve lecture presentations, homework assignments, demonstrations, and laboratory exercises. All of those items were a platform for this book.

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Chapter 7

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Introduction

Carbohydrates are major components of foods, accounting for more than 90% of the dry matter of fruits and vegetables and providing for 70–80% of human caloric intake worldwide (BeMiller and Huber 2008). Thus, from a quantitative perspective alone, carbohydrates warrant the attention of food chemists. From the standpoint of food quality, carbohydrates are multifunctional. Sugars are the major source, as well as our reference point, for sweetness. Although carbohydrates are described as being odorless, the volatile reaction products from the Maillard reaction, Strecker degradation, and carmelization reactions can provide desirable, undesirable, or neutral flavor compounds. And, although carbohydrates are colorless, sugars participate in Maillard and carmelization reactions to produce desirable and undesirable brown colors. Cellulose, hemicellulose, pectin, and starch are the structural components of plants that are largely responsible for the textural characteristics of fruits and vegetables. Starch and starch derivatives and various hydrocolloids isolated from plants, seaweed, and microbial sources are used as thickeners, gelling agents, bodying agents, and stabilizers in foods. When it comes to nutrition, a sizable portion of the lay public view carbohydrates in a bad light. Carbohydrates are often blamed for health issues such as obesity, diabetes, and dental caries. It should be realized that carbohydrates are, or should be, the principal source of energy in our diet. After all, we evolved as a species to efficiently use carbohydrates that can be converted to glucose for our body's fuel. Good nutrition is based on the consumption of the appropriate carbohydrates in the right amounts in balance with other nutrients. It is widely accepted that consumption of various forms of complex carbohydrate can reduce the risk of diabetes, coronary heart disease, diverticulitus, and colon cancer. For peak athletic performance, the advice of professional nutritionists will emphasize consumption of the appropriate carbohydrates, in the appropriate amounts, at the appropriate time. Although the percentage of carbohydrates contributing to caloric intake in the United States is highly variable, the average is considerably less than 70%. Dietary recommendations call for increased consumption of fruits and vegetables and a greater proportion of complex carbohydrate (Walker and Reamy 2009; WHO 2010).

The major thrust of this book is to apply basic carbohydrate chemistry to the quality attributes and functional properties of foods. Structure and nomenclature of sugars and sugar derivatives is covered but limited to those compounds that exist naturally in foods or are used as food additives and food ingredients. Review and presentation of fundamental carbohydrate chemistry is minimized, with the assumption that readers have taken general organic chemistry and general biochemistry and have ready access to those books for reference. Chemical reactions focus on those that have an impact on food quality and occur under processing and storage conditions. How chemical and physical properties of sugars and polysaccharides affect the functional properties of foods is emphasized. Taste properties and nonenzymic browning reactions are covered. The nutritional roles of carbohydrates are covered from a food chemist's perspective. One chapter describes selected carbohydrate analytical methods, emphasizing the basic principles of the methods and their advantages and limitations. There is an extensive appendix that includes some laboratory and classroom exercises and lecture demonstrations.

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1 Classifying, Identifying, Naming, and Drawing Sugars and Sugar Derivatives

Food Carbohydrate Chemistry, First Edition. Ronald E. Wrolstad.

Structure and Nomenclature of Monosaccharides

Sugars are polyhydroxycarbonyls that occur in single or multiple units as monosaccharides, disaccharides, trisaccharides, tetrasaccharides, or oligosacharides (typically three to ten sugar units). Monosaccharides (also known as simple sugars) exist as aldoses or ketoses, with glucose and fructose being the most common examples. **Glycose** is a generic term for sugars. Sugars are also classified according to the number of carbon atoms in the molecule (e.g., trioses, tetroses, pentoses, hexoses, heptoses, etc.).

Aldoses and Ketoses

Aldoses contain an aldehyde functional group at carbon-1 (C-1), whereas ketoses contain a carbonyl group that is almost always located at carbon-2 (C-2). C-1 for aldoses and C-2 for ketoses are the reactive centers for these molecules and are known as the **anomeric carbon atoms**. Figure 1.1 shows the structure for D-glucose, D-fructose, and, in addition, D-arabinose. Sugars have common or trivial names with historical origins from chemistry, medicine, and industry. There is also a systematic procedure for naming sugars (some examples are shown in Table 1.1). Glucose is also commonly known as dextrose. In systematic nomenclature, its suffix is hexose, indicating a 6-carbon aldose sugar, and the prefix is *gluco-*, which shows the orientation of the hydroxyl groups around carbons 2–5. The symbol D refers to the orientation of the hydroxyl group on C-5, the

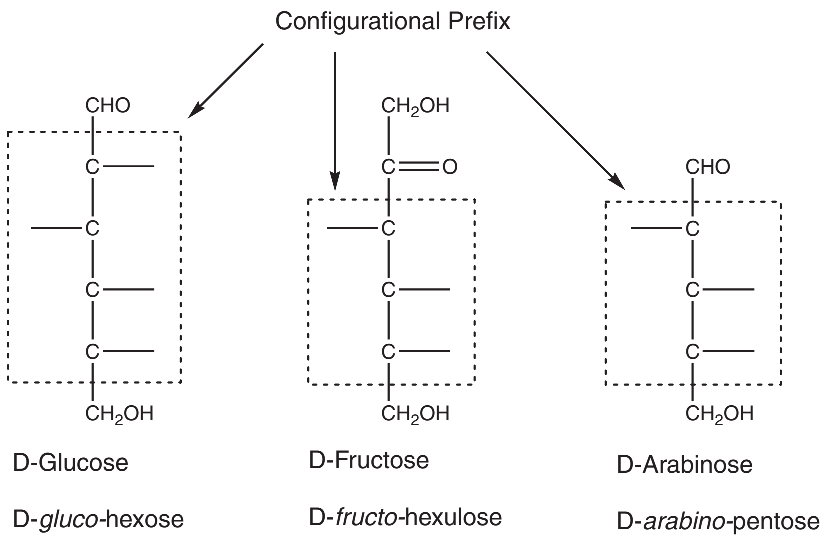

Figure 1.1 Structure and nomenclature of glucose, fructose, and arabinose.

Table 1.1 Trivial and Systematic Names of Selected Sugars

Trivial (or Common)	Systematic[a]
D-Erythrose	D-*erythro*-tetrose
D-Threose	D-*threo*-tetrose
D-Arabinose	D-*arabino*-pentose
D-Lyxose	D-*lyxo*-pentose
D-Ribose	D-*ribo*-pentose
D-Xylose	D-*xylo*-pentose
D-Allose	D-*allo*-hexose
D-Altrose	D-*altro*-hexose
D-Galactose	D-*galacto*-hexose
D-Glucose	D-*gluco*-hexose
D-Gulose	D-*gulo*-hexose
D-Idose	D-*ido*-hexose
D-Mannose	D-*manno*-hexose
D-Talose	D-*talo*-hexose

[a]In the systematic name, the configurational prefix is italicized, and the stem name indicates the number of carbon atoms in the molecule.

highest numbered asymmetric carbon atom, also known as the **reference carbon atom**. Since fructose (also known as levulose) has just three asymmetric carbon atoms, its configurational prefix is the same as that for the pentose sugar arabinose. Thus, the systematic name for glucose is D-*gluco*-hexose and fructose is D-*arabino*-hexulose.

Configurations of Aldose Sugars

Figure 1.2 shows all possible configurations around the asymmetric carbon atoms for the triose, tetrose, pentose, and hexose D-aldose sugars. **Diastereoisomers** are molecular isomers that differ in configuration about one or more asymmetric carbon atoms; there are eight hexose diastereoisomers. **Epimer** is yet another term in sugar chemistry that refers to diastereoisomers that differ in configuration about only one asymmetric carbon atom (e.g., D-galactose is the 4-epimer of D-glucose). The term has historical significance because the melting point of dinitrophenylhydrazone derivatives was a classical procedure used in identifying sugars. The 2-epimers (e.g., glucose and mannose, allose and altrose, etc.) gave identical dinitrophenylhydrazone derivatives.

D- vs. L-Sugars

L-sugars are the mirror images of D-sugars. Figure 1.3 depicts the structures of D- and L-glucose in the Fischer and conformational projections. (Note: When drawing an L-sugar, the orientation of the hydroxyl groups