rs.com, for detailed information on nutrition books, visit our website www.jaypeebrothers.com, for detailed information on nutrition book

Textbook of Human Nutrition



(Late) Anjana Agarwal
Shobha A Udipi



SECOND EDITION

Foreword
Poonam Agrawal

JAYPEE

Contents

1. FOOD, NUTRITION, AND HEALTH 1

What is Food? 2
What is Nutrition? 2
What are Nutrients? 3
Phytochemicals 5
Food Choices 5
Good Nutrition and Malnutrition 11
Strategies to Combat Malnutrition 17
Health 18

2. CARBOHYDRATES 21

What are Carbohydrates? 21
Functions of Carbohydrates 21
Classification of Carbohydrates 22
Recommended Dietary Allowance for Carbohydrates 33
Food Sources of Carbohydrates 34
Consequences of Inadequate Carbohydrate Intake 34
Consequences of Excessive Intake of Carbohydrates 35
Glycemic Index 40
Sugar Substitutes/Sweeteners 43
Digestion and Absorption of Carbohydrates 43

3. PROTEIN AND AMINO ACIDS 46

Proteins 46
Amino Acids: The Basic Building Blocks 52
Proteins in Food 53
Recommended Dietary Allowances for Protein 55
Food Sources of Protein 56
Deficiency of Protein: Its Causes and Consequences 57
Consequences of Excessive Intake of Protein 59
Protein Homeostasis 60
Nitrogen Balance 61
Evaluation of Protein Quality 61
Peptides 63
Roles of Individual Amino Acids or Functions of Amino Acids 66
Digestion of Proteins 72

4. FATS, OILS, AND LIPIDS 77

Introduction 77
Functions of Fats and Lipids 78
Classification of Fats, Oils, and Lipids 79
Lipids and Adipose Tissue 86
Derived Lipids 86
Fatty Acids 91
Essential Fatty Acids 98
Recommended Dietary Allowance of Fats and Oils 105
Food Sources of Fats and Oils 107
Consequences of Insufficient Intake of Fats and Oils 108
Consequences of Excessive Consumption of Fats and Oils 108
Ways to Reduce Fat Intake 109
Adverse Effects of Using Rancid or Reheated Oils 109
Fat Replacers 110
Digestion and Absorption of Fat 113
Absorption 113

5. ENERGY METABOLISM, ENERGY BALANCE AND BODY WEIGHT 116

What Is Energy? 116
Energy Metabolism 117
Energy Balance 120
Energy Expenditure 120
Energy Requirements 127
Energy Intake 129
Eating Disorders 133
Body Composition 134
Body Weight 141
Body Types 143

6. VITAMINS 149

Classification of Vitamins 149
Functions of Vitamin A 152
Vitamin K 164
Water-Soluble Vitamins 166
Vitamin-Like Compounds 184

7. MINERALS 192

Classification of Minerals 192
Trace Elements 208

8. WATER, ELECTROLYTES AND ACID-BASE BALANCE 240

Components of Body Fluids 241
Water Balance 243
Water Imbalance 247
Water Intoxication 250
Electrolytes and Electrolyte Balance 250
Acid–Base Balance 258
Role of Lungs and Kidneys in Maintenance of Acid–Base Balance 261

9. RECOMMENDED DIETARY ALLOWANCES AND DIETARY GUIDELINES 265

Recommended Dietary Allowances (RDA) 267
Dietary Guidelines 273
Food Guide for Indians 276
Food Groups 279

Use of Food Composition Tables 281
Meal Planning for Nutritionally Adequate Diets 282
Daily Meals 284
Percentage of Contribution of Different Nutrients 286
Daily Value (DV) 287
Nutrient Density 288

10. FOOD EXCHANGES 293

Food Exchanges 293
Food Exchange Lists 294

11. NUTRITION AND DIETARY CONSIDERATIONS AT DIFFERENT LIFE STAGES 304

Growth 305
Development 305
The First 1000 Days 306
Pregnancy and Fetal Development 307
Lactation 319
Breastfeeding 321
Childhood Years 323
Adults 340
Old age 342

12. NUTRITION IN DEFICIENCY DISORDERS AND SOME DIET-RELATED DISEASES 348

Protein–Energy Malnutrition (PEM) 349
Assessment of Nutritional Status 353
Moderate Acute Malnutrition (MAM) 353
Severe Acute Malnutrition (SAM) 353
Prevention and Control of Protein-Energy Malnutrition (PEM) 354
Vitamin A Deficiency 355
Iodine Deficiency Disorders 358
Nutritional Anemia 361
Overweight and Obesity 367
Diabetes 373
Hypertension 380
Osteoporosis 382

13. ASSESSMENT OF NUTRITIONAL STATUS 389

Nutritional Status 389
Anthropometric Measurements 394
Skinfold Measurement 398
Protein Status 402
Clinical Assessment 409
Dietary Assessment 411
Innovative Methodologies for Dietary Intake 413
Nutritional Assessment of Hospitalized Patients 415
Nutritional Assessment in Pediatric Population 417
Nutritional Screening and Assessment in Geriatric Population 418

14. ENSURING FOOD AND NUTRITIONAL SECURITY: NEW TECHNOLOGIES 420

Dimensions of Food Security 423
Nutrition Security 424
Technologies for Food and Nutrition Security 426
National Programs to Ensure Food and Nutrition Security 440

15. NEW HORIZONS IN NUTRITION 447

Functional Foods 447
Nutraceuticals 448
Sports Nutrition 457
Ergogenic Aids 469
Nutrition at High Altitude 469
Nutrition in Space 471
Nanotechnology 474
Nutrigenomics and Nutrigenetics 476

16. NUTRITION AND HEALTH SIGNIFICANCE OF FOOD INGREDIENTS 481

Cereals, Millets, and their Products 482
Lesser Known Cereals or Pseudocereals 487
Ready-to-Use Cereal Products 488
Pulses, Legumes, Beans, and Peas 489
Vegetables 492
Fruits 499
Milk and Milk Products 506
Eggs 509
Fish and Seafoods 509
Meat and Poultry 510
Sugars and Sweeteners 511
Fats and Oils 512
Spices, Herbs, and Condiments 516

17. NUTRITIONAL IMPLICATIONS OF FOOD PROCESSING AND PACKAGING 523

Browning 524
Nutrition Aspects of Different Methods of Food Processing 529
Novel Food Processing Technologies 548
Packaging 549
Packaging Materials and their Impact on Nutrition and Safety 550
Bio-based Packaging and Edible Films 551
Types of Food Packaging 551
Packaging for Different Types of Foods 552

APPENDICES 557

Appendix 1: *Food Sources of Energy (100 g edible portion) 557*
Appendix 2: *Dietary Fiber in Common Foods (100 g edible portion) 560*
Appendix 3: *Energy Requirements of Indian Men and Women at Different Ages and Body Weights 562*
Appendix 4: *Summary of Estimated Average Requirements (EAR) for Indians–2020 563*
Appendix 5: *Glycemic Index and Glycemic Load of Some Commonly Consumed Foods and Food Preparations 564*

Index *567*

2 CHAPTER

Carbohydrates

KEY CONCERNS
- What are the different types of carbohydrates?
- Will carbohydrate from different sources affect my health?
- What is dietary fiber and what is its role in health and disease?
- How much carbohydrate is present in various foods?
- What are sugar alcohols and artificial sweeteners?
- Why are glycemic index and glycemic load important?

KEY CONCEPTS
- Classification of carbohydrates
- Function of carbohydrates, their sources, and nutritional value
- Role of starch and dietary fiber in health and disease
- Causes and consequences of deficiency and excess
- Role of sugar alcohols and artificial sweeteners
- Significance of glycemic index and glycemic load.

Carbohydrates are the most abundant and relatively less expensive sources of energy. Across the globe, regardless of religion and race, carbohydrates supply almost half to three-fourths of the energy intake of individuals. This is because staple foods like cereals are good sources of carbohydrates. Carbohydrates form the building blocks of plants. Most plant foods contain a variety of carbohydrates in varying amounts whereas animal food sources contain only small amounts. Carbohydrates are sugars, starches, pectin, cellulose, and other compounds. Animals store some carbohydrate in the form of glycogen.

WHAT ARE CARBOHYDRATES?

- Carbohydrates are organic compounds. They are composed of carbon, hydrogen, and oxygen in a ratio of 1:2:1. Carbohydrates are hydrates of carbon because the general formula is $(CH_2O)_n$.
- In plants, carbohydrates are synthesized by **photosynthesis** in the presence of sunlight using carbon dioxide and water.

$$6CO_2 + 6H_2O + \text{Sun Energy} \xrightarrow{\text{Photosynthesis}} C_6H_{12}O_6 + 6\,O_2$$

Carbon dioxide + Water (+ Light Energy) = Glucose + Oxygen

- They are based on a common unit with varying linkages and chain lengths. Thus glucose is $C_6(H_2O)_6$.
- Some carbohydrates also contain other elements like nitrogen. The unit (monomer) of carbohydrates is generally **"Glucose",** which is the major source of energy for all vital activities in the body and also for the brain.

FUNCTIONS OF CARBOHYDRATES

Most carbohydrates are sweet in taste and improve palatability of the food. In most cultures, sweets are served on special occasions. Foods rich in sugar are a mark of respect and prosperity. Most staple foods are good sources of carbohydrates and are consumed to satisfy hunger. Carbohydrates perform several important functions in the body:

- **Provide energy**: One gram of carbohydrate provides 4 kcal. Carbohydrates are metabolized in the body (in the cell) in the presence of oxygen to give adenosine triphosphate (ATP).
- **Determine the sensory qualities**: Carbohydrates greatly influence the flavor, texture, and acceptability of the food.
- **Storage form of energy**: Carbohydrates are stored in the body in the form of glycogen in liver and muscles.
- **Source of carbon**: Carbohydrates supply carbon for the synthesis of cell components like DNA and RNA. Ribose is a five-carbon unit present in DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). Some carbon units from carbohydrates are used to synthesize nonessential amino acids. They are intermediates in the synthesis of the biochemical compounds such as lipids and proteins. Also, carbohydrates are part of free nucleotides, i.e., ATP and ADP, as well as coenzymes, i.e., nicotinamide adenine dinucleotide (NAD) and flavine adenine dinucleotide (FAD).
- **Cellular functions**: They participate in biological transport, cell–cell recognition, activation of growth factors, modulation of the immune system, as well as gene expression.
- **Carbohydrates are present as glycans on the cell surface**: Oligosaccharides, glycoproteins, and glycolipids are present and this diverse mixture of glycans contains a wealth of information, modulating a wide range of processes such as cell migration, proliferation, transcriptional regulation, and differentiation.
- **Formation of adipose tissue**: Excess carbohydrate is converted into fat and deposited in adipose tissue. Adipose tissue provides insulation and protects the various organs.

JAYPEE BROTHERS

However, excess of adipose tissue can result in overweight and obesity, diabetes, heart problems, and many other chronic diseases.

- **Protein sparing action**: Protein also provides 4 kcal/g; however, it is required for more important functions. When our diet supplies sufficient carbohydrates to meet the body's energy needs, it spares protein for its main functions. But if our intake is inadequate, then the body obtains the required energy from protein.
- **Health benefits**: Some indigestible carbohydrates are fermented by intestinal microorganisms. The products of fermentation have health benefits such as improving gastrointestinal health, immunity, and control diabetes and other metabolic diseases. They are useful in gut motility. They also have a role in blood clotting.
- **Prevent formation of ketone bodies/antiketogenic effect**: Carbohydrate is necessary for metabolism of fat. When there is insufficient carbohydrate, fat is utilized by the body for obtaining energy. However, a small amount of carbohydrate is required to break down fat completely. In the absence of carbohydrate, fat cannot be completely broken down and small compounds called ketones are formed. Most cells can utilize ketones for energy; however, excessive formation of ketone bodies is harmful.
- **Structural role**: They form structural tissues in plants (cellulose and lignin) and microorganisms. They are also constituents of cellular organelles and in combination with lipids and proteins; they provide structural integrity as well as mechanical strength. In cell membranes and membrane receptors, carbohydrates are part of glycoproteins and glycolipids.
- **Detoxification**: Many drugs and toxic molecules are metabolized in the body and converted into a form that can be excreted easily. Some of these molecules are not soluble in water and glucuronic acid is conjugated with these molecules to convert them to a more soluble form.

CLASSIFICATION OF CARBOHYDRATES

In chemistry, carbohydrates are also referred to as "**saccharides**". Saccharide is a Greek word which means "sugar". There is a wide variety of carbohydrates, ranging from simple compounds or sugars called monosaccharides to large complex molecules (polymers) called polysaccharides.

Monosaccharides are the basic units. Monosaccharides, i.e. glucose, fructose, and galactose are the building blocks of naturally occurring di-, oligo-, and polysaccharides.

When two monosaccharides are linked together, we get a disaccharide; three monosaccharides together give a trisaccharide. Oligosaccharides contain 3–10 monosaccharides and polysaccharides are large compounds or polymers containing numerous (>10) monosaccharides. The number of monosaccharides linked together is expressed as degree of polymerization (DP).

- Monosaccharides: Glucose, fructose, mannose, and galactose
- Disaccharides: Sucrose, maltose, and lactose
- Oligosaccharides: Raffinose, stachyose, verbascose, and fructo-oligosaccharides
- Polysaccharides: Starch, glycogen, cellulose, pectin, and non-starch polysaccharides.

Carbohydrates contain hydroxyl groups. In addition, they also contain either an aldehyde group or a ketone group. Therefore, carbohydrates are also either polyhydroxyaldehydes or polyhydroxyketones. Monosaccharides cannot be hydrolyzed further to simpler units.

In 1998, the Food and Agriculture Organization of the United Nations/World Health Organization (FAO/WHO) had classified carbohydrates based on the molecular size, which is determined by degree of polymerization (DP, i.e., the number of monosaccharides present in a carbohydrate), the type of linkages (α and β) and character of individual monomers (monosaccharides). This classification divides carbohydrates into three main groups, namely (1) sugars (also called simple sugars) **(DP 1–2),** (2) **oligosaccharides (short-chain carbohydrates) (DP 3–9) and** (3) **polysaccharides (DP ≥ 10**). The main categories of food carbohydrates are given in Table 2.1.

In 2006, a review commissioned by the FAO/WHO recommended the classification of carbohydrates that was based on their digestion and absorption in the small intestine rather than on their chemical characteristics. In 2007, FAO/WHO revised the classification of carbohydrates and recommended that it be based on degree of polymerization and the physiological and health effects. It has been recommended that carbohydrates as metabolizable substrate for energy be considered in terms of their gastrointestinal and metabolic fates. Nutritionally, carbohydrates are classified as:

- Digestible carbohydrates or available carbohydrates
- Nondigestible carbohydrates or unavailable carbohydrates

Table 2.1: Classification of carbohydrates based on degree of polymerization.

Class	Degree of Polymerization (DP)	Subgroups	Examples
Sugars	1	Monosaccharides	Glucose, fructose, and galactose
	2	Disaccharides	Sucrose, maltose, lactose, and trehalose
	1–2	Polyols (sugar alcohols)	Sorbitol, mannitol, lactitol, xylitol, maltitol, erythritol isomalt, and polyglycol
Oligosaccharides	3–9	Maltooligosaccharides	Maltodextrins
		Other oligosaccharides	Raffinose, stachyose, and fructooligosaccharides
Polysaccharides	>9	Starch (α-glucans)	Amylose, amylopectin, and modified starches
		Non-starch polysaccharide (NSP)	Cellulose (insoluble), hemicellulose (soluble and insoluble forms), pectin, gums, mucilages, and hydrocolloids

Scapin T, Fernandes AC, Proenca RPC. Added sugars: Definitions, classifications, metabolism and health implications. Rev Nutr. 2017;30(5):663–77.

JAYPEE BROTHERS

Table 2.2: Nutritional groupings of dietary carbohydrates based on physiological properties.

Nutritional groups based on physiological aspects	Dietary carbohydrate
Glycemic	Glucose, fructose, mannose, galactose, sucrose, maltose, lactose, trehalose, starch, and maltodextrins
Nonglycemic	Polyols (sugar alcohols), oligosaccharides (α-glucans), resistant and modified starches, and non-starch polysaccharides
Increase stool output	Polyols (except erythritol), some starches, NSP, lactose (in some populations), fructose (if taken in large amounts)
No effect on stool weight	Glucose, galactose, sucrose, maltose, trehalose, maltodextrins, oligosaccharides, most starches

Available carbohydrates: Available carbohydrates are those that are digested and absorbed in the small intestine. They include soluble sugars (mono- and disaccharides), maltodextrin, and starch (amylose and amylopectin). Those that have a glycemic effect whereas resistant carbohydrates are generally nonglycemic. Besides this, some of them will have positive effect on stool weight (Table 2.2).

Unavailable resistant carbohydrates: Unavailable resistant carbohydrates are the ones that resist digestion in the small intestine. Hence they are poorly absorbed in the intestines. They reach the human large intestine where they are partially fermented by the bacteria present in the colon. They include polyols (sugar alcohols), nondigestible oligosaccharides, fructans, non-starch polysaccharides (NSP), and resistant starch.

Carbohydrates vary in their source of supply, chemical structure, chemical reactions, chemical composition, and physical and physiological behavior. The properties of carbohydrates and how they are utilized in the body depends on the monosaccharide composition and how they are linked.

When one consumes carbohydrate, it raises the blood sugar/glucose levels after digestion and absorption. However, some carbohydrates or carbohydrate-containing foods will lead to a spike in blood sugar faster or earlier than others. Pure sugar, sweets, and white rice can raise sugar quickly, whereas pulses have a slower and smaller effect on blood sugar. Foods that contain disaccharides like sucrose and monosaccharides like glucose will raise blood sugar faster than those that contain complex carbohydrates. The amount of carbohydrate consumed also influences the extent to which blood sugar rises. Carbohydrates that raise blood sugar levels are known as **glycemic carbohydrates** and those that do not influence blood sugar levels are called **nonglycemic carbohydrates**. Nonglycemic carbohydrates generally remain unchanged in the small intestine and pass to the large intestines where they may be fermented to different extents by the microorganisms present.

Monosaccharides

Monosaccharides are the simplest form of carbohydrate. Monosaccharides are relatively small molecules, have low molecular weight, and are soluble in water. They are simple sugars. Most common monosaccharides contain 6-carbon units called hexoses and 5-carbon units called pentoses. Glucose, fructose, and galactose are examples of hexoses, and xylose and arabinose are examples of pentosans/pentoses. Since each monosaccharide is a primary form, they are seldom broken down by hydrolysis in the intestines. They are metabolized through metabolic pathways, e.g., glucose is metabolized through glycolysis to give ATP (energy) and pyruvic acid. Fructose can be converted into glucose.

They are commonly found in our regular diet and provide varying degres of sweetness to the food such as ripe fruits like banana, grapes, fruit juices, and also some seaweeds, yeast, fungi, etc.

They are major sources of fuel/energy and are required for biosynthesis of many molecules. Monosaccharides and disaccharides are easily absorbed and thus, rapidly raise blood sugar level. People having diabetes, obesity, and many other chronic diseases should avoid consumption of foods rich in simple sugars. It is recommended that only about 10% of dietary energy should come from simple sugars.



Glucose: Glucose is the principal form or basic building block of many carbohydrates such as starch, sucrose, glycogen, lactose, and maltose. Glucose is also formed during food processing or ripening of fruits. It is available in foods like fruits, sweet corn syrup, honey, and roots. It is an important monosaccharide because every other energy-yielding compound (except fat) must be converted into glucose first to obtain energy. It is a general precursor for many complex organic compounds in the body. Glucose is important for functioning of all tissues and is the prime fuel for brain, nerve cells, and red blood cells.

Excess of glucose is stored in the liver and muscles in the form of glycogen, and in adipose tissues in the form of triglycerides (fat). Glucose can enter cells with the help of the hormone "insulin", which is produced by the pancreas. The level of glucose in blood is used to indicate blood sugar level. Glucose is also required for synthesis of glycolipids, nucleic acids, and mucopolysaccharides.

Glucose in the blood is taken up by the body's cells and used to produce a fuel molecule called ATP through a series of complex processes known as cellular respiration. Cells can then use ATP to power a variety of metabolic tasks. Glucose is the form of carbohydrate that is utilized to produce energy by all cells but some organs must be supplied with glucose—these are brain, the medulla of the kidney, and red blood cells. The brain's requirement for glucose is about 140 g/day and that of anerobic tissues is approximately 40 g/day.

Fructose: It is also called fruit sugar because it is abundantly found in fruits, honey, and root vegetables. It is a component of sucrose (common or table sugar). Unlike glucose, fructose does not require insulin to be transported into muscles and

JAYPEE BROTHERS

fat cells. It is also part of fructooligosaccharides (FOS) and high-fructose corn syrup (HFCS). Relative sweetness of fructose (sweetest of all carbohydrates) is highest compared with other sugars. Fructose does not easily crystallize but absorbs moisture even at low relative humidity. Some fruits like dried fig and pear juice contain higher amounts of free fructose, which may cause some digestive disorders particularly among young children. In some cases, even in adults, fructose is not completely absorbed in the small intestine and reaches the large intestine intact, where it is fermented by microorganisms. The action of microorganisms results in gas formation causing bloating, and other digestive problems. Fructose is converted to glucose in the body through different biochemical pathway. Its excessive consumption may play a role in the emerging epidemic of obesity and associated disorders. Like glucose, fructose is also a source of energy.

Cells extract energy (in the form of ATP) from fructose only in the presence of oxygen that is called aerobic respiration. Although fructose gives the same amount of kilocalories as glucose, it is metabolized quite differently in the human body. After fructose is absorbed from the small intestines into blood, it is quickly taken up by the liver where a sizeable fraction (about one-third to one-half) is metabolized to glucose.

Fructose is first converted to fructose-1-phosphate, and further converted to glyceraldehyde and dihydroxyacetone phosphate. Both these products called triose phosphates are further metabolized by glycolysis. These triose phosphates may also condense together to form fructose-1,6-diphosphate, which is then converted through a series of steps to glucose-1-phosphate that is then used for producing glycogen (glycogenesis). Glycogen is the storage form of carbohydrate in mammals. Also, glucose can be produced from fructose but it does not contribute to the postprandial rise in blood sugar levels. Excess of fructose consumption leads to de novo lipogenesis (synthesis of fat molecules in the body), especially when it is consumed in liquid form. Hence it is a high risk for fatty liver and insulin resistance. There is no reverse mechanism for the fat that is synthesized from fructose to be converted back. Hence, it stays in the hepatocytes.

High-fructose corn syrup: This is a liquid sweetener used as an alternative to sucrose. It is manufactured from corn by chemical and enzymatic hydrolysis. The syrup that is obtained contains mostly glucose that then isomerizes to fructose, yielding HFCS. Three categories of HFCS are made—HFCS-90 contains 90% fructose and 10% glucose and is used in specialty applications. This is blended with glucose syrup to yield HFCS-42, containing 42% fructose and 58% glucose, and HFCS-55 that contains 55% fructose and 45% glucose. HFCS cost is relatively less than sugar. It is easy to use in soft drinks being in liquid form. It is slightly acidic so it has some preservative property. However, it is associated with increased incidence of obesity, diabetes, and other cardiovascular diseases, metabolic syndrome, and nonalcoholic fatty liver disease as well as high uric acid, it is associated health problems.

Research glimpse: High intake of added sugar (table sugar or sucrose) and high-fructose corn syrup have been found to result in obesity, metabolic syndrome, and diabetes. Such sugars usually come from sugar-laden beverages, fruit juices, etc. Fructose has the ability to cause intracellular ATP depletion and increased production of uric acid and has lipogenic effects at high concentrations. Fructose-induced uric acid generation causes mitochondrial oxidative stress that stimulates fat accumulation independent of excessive caloric intake.

Johnson RJ, Nakagawa T, Sanchez-Lozada LG, et al. Sugar, uric acid, and the etiology of diabetes and obesity. Diabetes. 2013;62(10):3307-15

Laboratory laurel: Abdominal adiposity and visceral adipose tissue (VAT) have been reported to be independent factors for the increased risk for diabetes and cardiovascular diseases. In a cross-sectional study with 2,596 middle-aged individuals, habitual consumption of sugar-sweetened beverages and diet soda (carbonated beverages) was recorded by Food Frequency Questionnaire and VAT was assessed using computed tomography. An inverse association was observed between consumption of sugar-sweetened beverages and abdominal subcutaneous adipose tissue (SAT), whereas it was positively associated with VAT after adjusting for SAT. Diet soda consumption was positively associated with SAT but not with VAT or the VAT to SAT ratio.

Ma J, Sloan M, Fox CS, et al. Sugar-sweetened beverage consumption is associated with abdominal fat partitioning in healthy adults. J Nut . 2014;144(8):1283-90

Mannose: Mannose, another monosaccharide, occurs freely in nature and is found in cranberries, red currants, black currants, peaches, gooseberries, aloe vera, soybeans, cabbage, beans, brinjal, capsicum, turnip, tomatoes, and broccoli. Fenugreek seeds contain a high amount of galactomannan, a polysaccharide, comprised of galactose and mannose. Mannose is absorbed eight times more slowly than glucose but reaches directly into the bloodstream and is distributed throughout the body tissues and fluids. Mannose is part of compounds called acute-phase proteins such as mannose-binding lectin (MBL) and mannose-binding protein (MBP). These are produced by the liver in response to infection and are important for innate immunity. During infection, bacteria tend to adhere to the epithelial lining of the target cells. However, in presence of mannose, bacteria attach themselves to the mannose molecules instead of adhering to the lining. Both bacteria and the mannose molecules are then expelled from the body, eliminating or reducing the chances of infection.

Laboratory laurel: The mannose-binding lectin (MBL) belongs to the innate immunity system and recognizes and binds a variety of pathogens and thus protects the host. The genetic, biologic, and clinical properties of MBL have been studied intensively, although many aspects of its clinical relevance still remain to be discovered. MBL may serve as the first line of defence in the neonate whose own immune system is compromised. It may also be involved in neuronal migration, interneuronal recognition, and myelinization. Thus low MBL levels may increase risk of infections. However, given that MBL production is uncontrolled in some disorders, replacement therapy of MBL needs to be studied thoroughly and intensively before it is used especially for critically ill infants.

Auriti C, Prencipe G, Moriondo M, et al. Mannose-binding lectin: Biological characteristics and role in the susceptibility to infections and ischemia-reperfusion related injury in critically ill neonates. J Immunol Res.2017:7045630.

JAYPEE BROTHERS

Galactose: Galactose is a component of lactose (milk sugar), but it is not available freely in nature. It is found not only in dairy products (all milks) and some hard cheeses, but also in some plant-based foods such as beans, lentils, sugar beet, avocado, bell pepper, papaya, watermelon, dates, mushrooms, olives, peanuts, as well as organ meats like liver, brain, and kidneys. All food items made from milk will contain galactose in small or relatively larger amounts. Galactose content ranges from less than 0.1 mg per 100 g of tissue in artichoke, mushroom, olive, and peanut to 35.4 mg per 100 g in persimmon. Fruits and vegetables like date, papaya, bell pepper, tomato, and watermelon contain more than 10 mg per 100 g. Galactose is a part of glycolipids and glycoproteins, which are present in cell membranes. Galactose in glycolipids is an essential component of the antigen that determines the blood groups (A, B, AB, and O). In liver, it is converted into glucose to release energy. It also supports the synthesis of gangliosides, which are primarily found in the myelin sheath around nerve fibers. Galactose has an important role in mitigating the growth of tumor cells and facilitating the immune process. In some body cells and connective tissues, it is present as galactosamine, glycoprotein, and mucopolysaccharides. Galactosemia is an inborn error of metabolism in which the individual lacks the galactose-1-phosphate uridyltransferase enzyme. This enzyme is necessary to break down the galactose into the glucose. Deficiency of this enzyme can cause galactosemia, an inborn error of galactose metabolism. Hence, there is a buildup of galactose in the blood which subsequently damages the liver, eyes, kidney, and brain. A person suffering from galactosemia needs to essentially live on a lactose-free and galactose-free diet throughout life.

Disaccharides

Disaccharides are composed of two monosaccharides linked together by *O*-glycosidic bond in which the oxygen from a hydroxyl group becomes linked to the carbonyl carbon. Different monosaccharides in varied combinations give different disaccharides. Three disaccharides are commonly known, namely sucrose, lactose, and maltose. Others are lactulose, trehalose, cellobiose, and chitobiose. These two types of disaccharide, e.g., lactose and lactulose contain same monosaccharides but differ in their basic structure, solubility and digestibility. Lactose is a milk sugar while lactulose is used as medicine in the treatment of constipation. Some uncommon disaccharides are isomaltose, turanose, melibiose, mannobiose, xylobiose and sophorose. Sucrose is composed of glucose and fructose; lactose is made up of glucose and galactose while maltose is a mix of two units of glucose only. In all three disaccharides, glucose is present. Disaccharides are soluble in water and sweet to taste, although they differ in their sweetness. They are freely found in nature (food). During digestion, disaccharides are hydrolyzed into their constituent monosaccharides, by the action of specific enzymes. Before they release energy, they need to be converted into glucose through metabolic reactions.

Sucrose: Sucrose, the most commonly used sugar, is also called table sugar. It is basically obtained from sugarcane and sugar beet. The white sugar crystals, we are familiar with, are obtained after processing and refining the juice. It is also found in many other foods like banana, dates, pineapple, peas, and sweet potato. Besides being used as a sweetener, sucrose is used as a preservative at high concentrations (>50%) in jams, jellies, and squashes. Sugar keeps things moist as it absorbs moisture easily (substances that are used to keep foods or other things moist are called humectants). It can easily be crystallized and caramelized and hence is used to make a wide variety of sweets and candies. However, sucrose is the main culprit in development of several health problems like tooth decay, skin problems, obesity, insulin resistance, diabetes, heart disease, etc. Since sucrose adds taste and flavor to food, persons of all ages tend to overconsume sugar-containing foods, gradually gain weight, and their risk for developing diabetes and/or heart disease increases.

Maltose: Maltose contains two molecules of glucose. It is not freely present in raw foods; rather it is produced when grains are malted or when foods are fermented. Malting is the process in which cereal/millet grains or pulses are sprouted and dried. During sprouting (germination), the cereal starch is converted into maltose by the action of the enzyme, α-amylase and gives rise to a typical flavor. Maltose is easily digestible. Malting is a process used to develop infant foods and amylase-rich foods (ARF) as well as to produce beer from barley.

Lactose: Lactose is composed of glucose and galactose. Lactose is not found in plant foods. It is synthesized in mammary glands where glucose is converted into galactose and then combined with glucose to produce lactose in the milk. Thus lactose is also called milk sugar. Mother's milk contains significant amount of lactose which is a major source of energy for infants. Lactose also helps in the absorption of calcium. Lactase, an enzyme present in the intestines, breaks down lactose into glucose and galactose, which are then absorbed. In the early years of life, lactase is present in sufficient amounts. However, as a person grows older, the synthesis of this enzyme by the intestines decreases. Thus for some people, digestion of milk becomes difficult as age progresses, due to lower amount or lack of lactase enzyme. Persons who cannot digest lactose (milk) are called lactose intolerant. For such persons, there are enzyme preparations available in the market. For lactose-intolerant infants, special formulas without lactose can be used.

Lactose intolerance: Lactose intolerance is a clinical syndrome, which occurs in absence of the enzyme lactase, in the small intestine. Lactase helps to digest lactose present in milk. If lactase is deficient, digestion of lactose and milk is hampered. The symptoms are abdominal distension, cramps, and diarrhea. Lactose deficiency can be overcome by:

1. Removal of dairy products from the diet
2. Use of fermented dairy products like curd, where lactose is converted into lactic acid.
3. Addition of *Lactobacillus* or probiotics in the diet which help in digestion of lactose. They act in the large intestine in presence of gut flora.
4. Commercial preparations that are lactose free.

JAYPEE BROTHERS

Dairy products like curd can be considered for persons having lactose intolerance. Such products are prepared by fermentation using starter culture of *Lactobacillus* sp., which converts lactose into lactic acid (due to which curd is sour). Such products are better digested than milk and beneficial for health in other ways. There is a probiotic effect of curd or yoghurt. Plant-based milk like soy milk, nut milk, and wheat milk can be suggested to lactose-intolerant people.

Sugar Alcohols or Polyols

Sugar alcohols
- Sorbitol
- Mannitol
- Xylitol
- Lactitol
- Maltitol
- Isomalt
- Erythritol
- Hydrogenated starch hydrolysate or polyglucitol

Sugar alcohols are also known as "polyols" and have a Degree of Polymerization (DP) of 2. Sugar alcohols are derived from simple carbohydrates by substitution of the aldehyde group by a hydroxyl group. Some of them are naturally present in some fruits, e.g., sorbitol in plums. They are also synthesized commercially and are used in foods, beverages, and by the pharmaceutical industry. They are slowly or not completely absorbed by the human body. Therefore, they are used as alternative sweeteners as they do not raise blood sugar to the same extent that table sugar does, do not require insulin in order to be metabolized, and they provide less or negligible calories (0–3 kcal per gram). Their sweetness varies from 25% to 100% of the sweetness of sugar, i.e., sucrose. Thus they are good for diabetics and those who want to restrict sugar consumption. They are often used in combination with other sweeteners to obtain the desired flavor and sweetness.

In the food industry, they are being substituted for sugar or corn syrup in development of many dietetic foods. This is because they have a mild sweet taste which can be used in the same volume as sugar and can add bulk to the food while giving almost half the amount of calories compared with sugar. Besides adding bulk, they also provide mouthfeel. Substitution for sugar or corn syrup can be done in a 1:1 ratio. They can be used to replace part or all the sugar in a food product giving low-sugar or sugar-free products. They decrease water activity in "intermediate moisture foods" and depending on the specific alcohol are used as softeners, glazing agents, humectants, stabilizers, thickeners, sequestrants, emulsifiers, anticaking agent, and rehydration of dehydrated food.

Polyols can also serve as prebiotics. However, their slow digestibility can also cause some gastric disturbances (gas and bloating) and have laxative effect if used in excess (more than 50 g a day). Therefore, these sweeteners need to be used in moderation and under guidance. They generally do not cause dental caries. Some of the sugar alcohols are discussed below:

Sorbitol: It is naturally present in fruits like pears, apples, peaches, apricots, and nectarines and plums as well as in dried fruits, such as prunes, dates, and raisins, and in some vegetables. Industrially, it is produced from either glucose or sucrose either in liquid or crystalline form. It is 60% as sweet as sucrose and provides 2.6 kcal /g. It is hygroscopic, chemically inert and stable and unlike sugar or glucose does not undergo Maillard reaction. Its glycemic index is 9. It gives a cooling sensation in the mouth and has a sweet and cooling taste. It is the most commonly used polyol that is derived from glucose.

Its digestion is rather slow; it is not well absorbed in infants, small children, and many adults. It ferments in the large intestine, producing gas, bloating and cramps or osmotic diarrhea or laxative effect on excessive intake (>10–30 g/day). Sorbitol is converted to fructose in the body. It is commonly used to make sugar-free food products such as hard candies, chewing gums, frozen desserts, baked goods, and other delicacies. It is used as a humectant to prevent loss of moisture from the food product in which it is used. It is also used to prevent crystallization.

Mannitol: Mannitol is present in pineapple, olive, sweet potato, and carrot. It is an isomer of sorbitol and is commercially manufactured by hydrogenation of specialty glucose syrups or glucose and fructose in a 1:1 mixture. In nature, mannitol is present in the exudates of some trees, and is present in some edible fungi and seaweed. Mannitol has about 50% of the sweetness of sugar; it is also converted to fructose but yields 2.1–2.4 kcal/g. Mannitol is not absorbed and hence does not cause much increase in blood glucose. Its glycemic index value is 0. Orally it has a cooling effect (but this is much less than that of other polyols) and helps to mask bitter taste.

It is not hygroscopic and is stable at high temperatures, therefore, used as a dusting powder for chewing gum to prevent sticking to wrappers or to the manufacturing equipment. It is also used in sugar-free hard candies, chocolates, and ice-cream, as well as in pharmaceuticals and nutrient tablets. Beisdes being used as a sugar substitute, it can be used as a fat substitute because it imparts a creamy texture to foods especially for preparation of low sugar and low-fat bakery foods. However, consumption of more than 10–20 g/day mannitol may cause gastric disturbances, diarrhea. Mannitol is an osmotic diuretic and is used clinically to reduce intracranial pressure and treat oliguric renal failure. Large doses of mannitol may increases excretion of sodium and potassium.

Xylitol: Xylitol is a five-carbon alchohol, produced from D-xylose and yields 2.4 kcal /g. Since its discovery in 1960s, it has been used as a sweetener. Its glycemic index is 13. It has very cooling sensation in mouth. Its major advantage is that it is not attacked by cariogenic bacteria, thus it inhibits tooth decay and formation of plaque. It is naturally found in plums, cherries, and berries as well as in some vegetables and oats. It is absorbed 50% in the small intestine, has the same sweetness as sucrose as well as bulk. It is the sweetest among the sugar alcohols. Use of xylitol is common in chewing gum and many dietetic products. Insulin is not required for its metabolism.

JAYPEE BROTHERS

Laboratory laurel: Xylitol has been used as a sugar substitute and is well known for its ability to prevent tooth decay. Hence, it has been used as an ingredient in chewing gum, because organisms such as *Streptococcus mutans* that cause cavities and dental caries cannot use xylitol as a source of energy. In this study, the effect of dietary xylitol was studied on influenza A virus infection (H1N1) in a mouse model. It was observed that survival of mice was enhanced when xylitol was administered with red ginseng, suggesting that there is a synergistic effect. Also with increasing dose of xylitol, the effect increased. Further, dietary xylitol together with the water- soluble fraction of red ginseng significantly reduced the lung virus titers after infection.

Yin SY, Kim HJ, Kim HJ. Protective effect of dietary xylitol on influenza a virus infection. PLoS One. 2014;9(1):e84633.

Lactitol: It is 40% sweet as sucrose and yields 2.0 kcal/g. It is obtained from hydrogenation of lactose from milk. Its glycemic index is 6. It has a clean and mild sweet taste but has no aftertaste and cooling effect. Hence, it is often mixed with other sweeteners and is used as a thickener and emulsifier. Therapeutically, it is used for treating constipation in adults and older persons. Lactitol is observed to be more efficacious than lactulose. It is fermented by colonic bacteria and has a prebiotic effect. Common uses are as an ingredient in candies, chocolates, cookies, and cakes especially for diabetics as well as in low-calorie, low-fat and/or sugar-free foods including ice-creams, reduced-sugar preserves, and chewing gums.

Maltitol: Its sweetness is about 90% of the sweetness of sucrose/sugar but provides only 2.1 kcal/g. It is a disaccharide polyol consisting of glucose and sorbitol in equal part. It is produced by hydrogenation of high-maltose corn syrup or from starch. Its glycemic index is 35. Compared with the other polyols, it resembles sucrose the most in terms of characteristics. It is used with short-chain fructooligosaccharides (FOS) in production of sugar-free foods. Maltitol is used in coatings, chewing gum, jam, gelatin, and jelly. However, maltitol has a laxative effect; therefore, consumption should be limited. It may also be used to replace fat as it gives a creamy texture to food. Hence, it is suitable for making varied bakery products, especially because it is stable at high temperatures and has low hygroscopicity.

Isomalt: Isomalt is a bulk sweetener made from sucrose and can be used as replacement for sucrose. Its glycemic index is 9. It is a mixture of gluco-mannitol and gluco-sorbitol. Its sweetness is 45–65% of sucrose but does not crystallize as easily as sucrose. Therefore, it is used in sugar sculptures and decorative edible products. It has a low glycemic effect. Toffees, lollipops, fudge, chocolates, wafers, and cough drops may have this low sugar/calories ingredient. Isomalt absorbs very little water. Therefore, products made with it tend not to become sticky but have a longer shelf-life. Isomalt enhances flavor transfer in foods. It dissolves more slowly in the mouth so that candies with isomalt have a longer-lasting taste. It is stable to heat, but unlike other alcohols does not give a cooling sensation in the mouth. It is also used as a bulking agent, anti-caking agent, and for glazing purposes. It is anticariogenic and it has been found in toothpastes containing isomalt, enhanced remineralization of teeth. Very small amount of this sugar alcohol is absorbed and about 90% is fermented in the large intestine. It is a good prebiotic because its fermentation yields the short-chain fatty acid—butyric acid. However, consumption of large amounts may lead to laxation.

Erythritol: It is regarded as a next-generation sweetener. It is a natural-occurring component of some vegetables, fruits like pears, melons, and peaches, mushrooms, fermented beverages like wine, beer, and soya sauce. It is also a bulk sweetener, its glycemic index value is 0, and it can easily be mixed with other sugar alcohols. It is almost completely absorbed but is minimally metabolized in the human body, is poorly reabsorbed by the kidney, and is excreted in urine.

This characteristic is attributed to its high stability in acid and alkali and hot environment/high temperatures typically used in food production, thus it is suitable for use in baked products. Its sweetness is close to sucrose, making and is useful in low-calorie foods. It gives negligible calories (0.2 kcal/g) and is 70% sweet as sucrose. It is safe, has no aftertaste, and has the mouthfeel of sugar. It provides good gloss and melting characteristics. It gives baking stability and shelf-life stability, and is used in cakes, cookies, and other baked goods. It provides good texture to foods like ice-cream.

It is rapidly absorbed and rapidly eliminated by the digestive system. It is also present in some tissues of the human body such as lens, cerebrospinal fluid, and serum. It has been shown to have radical scavenging properties. Unlike other polyols, it has a laxative effect only at very high dose of about 1,000 mg/kg of body weight.

Polyglycitol (hydrogenated starch hydrolysate): The names polyglycitol or hydrogenated starch hydrolysate or polyglucitol are used interchangeably. This is a large group of hydrogenated glucose syrups, maltitol syrups, and sorbitol syrups that are manufactured using corn, wheat or potato starch. When the product contains more than 50% maltitol on a dry basis, they are called maltitol syrups whereas polyglycitols are those that contain less than 50% maltitol. They provide approximately 90% of the sweetness of sugar. They are used for a variety of purposes such as imparting desired viscosity, as bulk sweeteners, humectants, and to prevent recrystallization (because they do not crystallize). Calorie content depends on the composition of the final product and it is often used to replace corn syrup; but in general, it does not give more than 3 kcal/g, usually 2.4 kcal/g.

The advantage of using these is that they are nonreactive with other ingredients and colorless and odorless, used in food formulations such as colors, flavors or enzymes. They also improve freeze-thaw stability of frozen foods. In the human body, these products are acted upon by enzymes and hydrolyzed to sorbitol, glucose, and maltitol and only about one-tenth is converted to monosaccharides that are absorbed. The undigested part is fermented by the colonic microorganisms. If these products are consumed on an empty stomach, many times a day, there can be a laxative effect. They also exert an osmotic effect. However, doses of up to 45–90 g/day have been found to be well tolerated and did not exhibit a glycemic effect, indicating that these are useful as sweeteners for diabetics.

JAYPEE BROTHERS

A Note of Caution: Sugar alcohols are readily converted to glucose in the liver, especially when blood sugar is already high and carbohydrate intolerance is out-of-control. They can also be converted to fat, and may contribute to high triglycerides (a heart disease risk) and weight gain. In addition, sugar alcohols are becoming better known for their potent laxative effect and digestive upsets. Also, new researches signal the association of polyols with peripheral neuropathy in diabetics.

Oligosaccharides

Oligosaccharides contain 3–9 monosaccharide molecules. Thus, their degree of polymerization is in between that of simple sugars and polysaccharides. Raffinose, stachyose, gentiobiose, and verbascose are naturally occurring oligosaccharides found in some plant foods like legumes and soybeans, and dairy products such as yoghurt. In general, they are much less sweet (0.3–0.6 times) than sucrose. Sweetness of oligosaccharides decreases with an increase in the chain length. They are not easily digested in the human small intestine because the enzymes necessary for their hydrolysis are not present. Hence, they enter the large intestine in undigested or partially digested state. They are fermented by the gut (colonic) microorganisms/flora, and often produce flatus (gas) which gives rise to a feeling of bloating, e.g., after consuming pulses or drinking milk in some people. Also oligosaccharides do not require insulin and thus can be used in dietetic foods. Thus they are used as bulking agents, humectants and as anticariogenic substances. Because they are not digestible, they possess properties like that of dietary fiber and prebiotics. There are a numerous functional oligosaccharides in the food industry as well as pharmaceutical industries such as fructooligosaccharides, glucooligosaccharides, isomalt-oligosaccharides, soybean-meal oligosaccharides, mannan oligosaccharides, galacto-oligosaccharides, gentio-oligosaccharides, isomaltulose, lactosucrose, maltooligosaccharides, xylooligosaccharides, pectin-derived acidic oligosaccharides, and cyclodextrins. In nature, a variety of plant sources contain oligosaccharides such as wheat, rye, barley, soybean, pulses, mustard, milk, honey, sugarcane juice as well as some fruits, and vegetables like onion, asparagus, sugar beet, artichoke, chicory, leek, garlic, tomato, banana, yacón, and bamboo shoots.

Research glimpse: Oligosaccharides are found in many types of bacteria, algae, fungi, and higher plants. They are not only used as food ingredients but also as pharmacological supplements. They possess functional properties of dietary fiber hence are beneficial in weight control. They behave as humectants so are useful in confectionery and baked goods. Being prebiotics they are effective in promoting the growth of normal intestinal flora/microorganisms and suppress pathogens. Other benefits include prevention of dental caries, facilitating mineral absorption, immunomodulatory action, and other potential therapeutic benefits such as anti-allergic, anti-inflammatory, antioxidant, and antiviral. These compounds are also being researched for their role in maintaining bone mass and density, apoptosis, antitumor/anticancer activity, and anti-obesity. In animal feed, oligosaccharides could serve as alternatives to antibiotics.

Patel S, Goyal A. Functional oligosaccharides: production, properties and applications. World J Microbiol and Biotechnol. 2011;27(5):1119–28.

Fructooligosaccharides: They are nondigestible oligosaccharides that occur naturally in various edible plant foods such as grains, fruits, and vegetables such as wheat, banana, sugar beet, onion, tomato, and garlic, although the amount is relatively small. FOS is mainly composed of fructose units and provides sweet taste and good flavor. Fructooliogosaccharides is a subgroup of inulin with the degree of polymerization ranging from 2 to 10. They are not digested in the small intestine and thus provide only 1 kcal/g. Because of their low caloric density, they have the potential to be used in a variety of products such as artificial sweetener/sugar replacement in pastries, chocolates, ice-creams, etc. Its viscosity and stability in refrigeration widen its scope in many other products. The added advantage is that they are not cariogenic.

They reach the colon intact, where they are fermented by the colonic microflora and promote growth of microorganisms in the colon. Thus, they promote growth of microorganisms in the large intestine thus exhibit prebiotic effect. The colonic organisms ferment the FOS, and one of the end products of fermentation is short-chain fatty acids, which in turn confer some health benefits by reducing the risk of inflammatory diseases such as type 2 diabetes, obesity, heart disease, by reducing the cholesterol, triglyceride and blood glucose levels. FOS also provides some protection against pathogens like *Salmonella* and other organisms causing foodborne illness and other digestive disorders.

Laboratory laurel: A randomized double blind crossover study was conducted to evaluate the impact of fructooligosaccharides (FOS) and galactooligosaccharides (GOS) on glycemic response on 35 adults. They were given FOS and GOS for 14 days (16 g/day) and tested for anthropometric measurements, oral glucose tolerance test (OGTT), and intestinal microbiota in feces samples. Short-term intake of high dose of FOS had adverse effect on glucose metabolism, as demonstrated by OGTT. With both FOS and GOS, significant increase in *Bifidobacterium*, and the butyrate-producing bacteria, *Phascolarctobacterium* in FOS group was observed while *Ruminococcus* in GOS group were decreased.

Liu F, Li P, Chen M, et al. Fructooligosaccharide (FOS) and Galactooligosaccharide (GOS) Increase Bifidobacterium but Reduce Butyrate Producing Bacteria with Adverse Glycemic Metabolism in healthy young population. Scientific Reports. 2017;7:11789.

Maltooligosaccharides (Maltodextrin): Maltodextrin, a polysaccharide, is manufactured by partial hydrolysis of any starch using water, enzymes, and acid obtained from natural sources like potato, wheat, corn, rice, and tapioca. Maltodextrin is an easily digestible carbohydrate consisting of D-glucose units. It may be moderately sweet or without any distinct flavor, hence it is generally not used as a sweetener but can help in incorporating spices into foods/recipes. It has good texturizing, gelling, emulsifying, and noncrystallizing properties. It is used in a wide variety of food products and beverages such as pasta, baked foods, desserts, and energy and sports drinks, including gluten-free, baby foods and dietetic food products. It is also used in pharmaceutical industry. They provide 4 kcal/g. Since it is a highly refined form of carbohydrate, it tends to raise the blood sugar level faster. Hence foods containing maltodextrin are

JAYPEE BROTHERS

not good for diabetes. In food industry instead of degree of polymerization (DP) use of maltodextin is taken on the basis of a different parameter known as dextrose equivalent (DE). It is a measure of the percentage of reducing sugars in the maltodextrin relative to the percentage in glucose (100%). DE can also be calculated as 100/DP. Higher DE have lower DP. For example DE values in the range of 18–22 are often used successfully in making of gluten-free breads that is high in baked volume and long shelf-life by slowing starch retrogradation.

Research glimpse: Human milk contains abundance of oligosaccharides (more than 100 different oligosaccharides) but newborns or infants cannot use them for energy purposes. However, human milk oligosaccharides (HMO) are very important because they support a healthy gut microbiome by stimulating the growth of beneficial microbes such as *Bifidobacterium*.

Thompson P, Garrido D. Chapter 5: Human Milk Oligosaccharides and health promotion through the gut microbiome. Dairy in Human Health and Disease Across the Lifespan. 2017:73-86.

Polysaccharides

Polysaccharides are also known as complex carbohydrates. Polysaccharides contain numerous monosaccharide units linked together by glycosidic linkage. They are naturally found in plants, algae, seaweeds, and animals. Majority of the carbohydrates in our diets are polysaccharides. Different polysaccharides occurring in nature are shown in Table 2.3.

Some polysaccharides are digested in the human gastrointestinal tract, whereas others are not. Starch is digested whereas cellulose, hemicelluloses, beta-glucans, pectins, lignin, gums are not digested, hence they are referred to as non-starch polysaccharides (NSP). Different polysaccharides are shown in Figure 2.1.

Table 2.3: Different polysaccharides in plants and animals.

Polysaccharides in plants	Polysaccharides in animals	Functions
Starch, dextrin, and inulin	Glycogen	Storage or reserve substances
Cellulose, hemicellulose, and pectin	Chitin in shells of crustaceans	Structure-forming substances
Pectin, agar, and alginate	Mucopolysaccharides in connective tissues	Water-binding substances

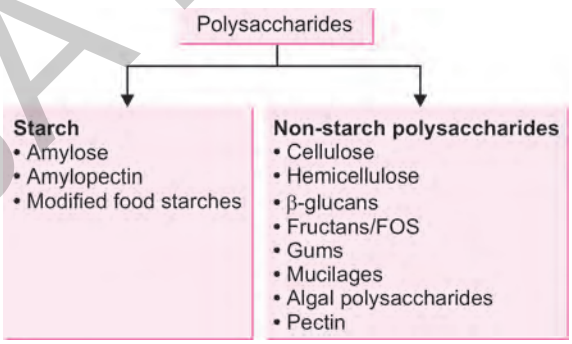

Fig. 2.1: Starch and non-starch based polysaccharides.

Non-starch polysaccharides do not provide energy because they cannot be digested in the small intestine due to lack of the necessary enzymes. These indigestible polysaccharides are important prebiotics because, like FOS, they are utilized by the intestinal microflora. Their action generates short-chain fatty acids namely acetic acid, butyric acid, and propionic acid, which have health benefits.

Polysaccharides vary in their solubility, digestibility, and physical and physiological impact. In natural form, most of them (except pectin and agar) are insoluble in water. Temperature, pH, moisture, and combination with other molecules bring drastic changes in these polysaccharides. These properties are extensively exploited in cookery for preparation of various food products. Many of them are valued for their nutritional significance.

Starch: Starch is the storage form of energy in plants. It consists of only glucose units linked by α-(alpha) glycosidic linkage in linear or branched chains. Starch is generally present as granules in the form of mainly two components namely amylose and amylopectin. Amylose is a straight (linear) chain (polymer) of glucose molecules and amylopectin is a branched chain of glucose units.

Amylopectin is branched with 1, 6 linkages as well as 1, 4 linkages and may comprise more than 100,000 glucose residues. Starches from different food sources differ in their physiochemical properties and behavior due to differences in the amount of amylose and amylopectin present. This difference is exploited in making a wide variety of food products. The difference in the structure of starch molecules can easily be seen under a microscope. Amylose and amylopectin content of different foods are shown in Table 2.4. Most starches consist of 20–30% amylose and 70–80% amylopectin but pseudocereals like amaranth and quinoa contain about 8–12% amylose. The proportion of amylose to amylopectin in most starches is 1:3, but some starches like waxy varieties of maize or rice contain amylopectin and little or no amylose (ranging from 0-30%). Basmati rice has intermediate value. Amylose content is significantly variable by variety of the grain and tubers, milling and cooking characteristics.

Table 2.4: Amylose and amylopectin in different sources of starch.

Source of starch	Amylopectin (%)	Amylose (%)
Rice	25	75
Wheat	24	76
Corn	28	72
Sorghum	22	78
Tapioca	17	83
Potato	22	78
Banana	21	79
Arrowroot	20	80
Sweet Potato	18	82
Waxy rice/corn	-	97–99

Source: Swaminathan M. Advanced Textbook on Food and Nutrition, Volume I. Bangalore: BAPPCO; 2002. p. 12

JAYPEE BROTHERS

All grains, i.e., cereals and millets, pulses/legumes, and roots and tubers like potato, sweet potato, yam and tapioca are rich in starch. Starch is hydrolyzed by digestive enzymes in the intestines. Digestibility of high-amylopectin foods is better than those foods that contain amylopectin and amylose. Hence foods having high amylopectin and/or less amylose raise the blood sugar level (higher glycemic index) faster than foods that are high in amylose, and the proportion of amylose to amylopectin has an impact on insulin response to a food item. Basmati rice has higher amylose content as compared with other local rice varieties.

Starch-rich foods are classified based on amylose content, e.g., normal barley contains 25–27% amylose; waxy type (non-detectable and below 5% amylose), and high-amylose type contain more than 35% amylose. The ratio of amylose and amylopectin is an indicator of glycemic index. Amylose content also determines the texture of final product. Hence amylose can be used as a thickener, bulking agent, gelling agent, and water absorbent in preparations of puddings, cookies, and drinks.

Carbohydrates but more specifically starch is categorized as slowly digestible starch (SDS), rapidly digestible starch (RDS), and resistant starch (RS) based on how rapidly digestion by intestinal amylase takes place and will influence or determine the rise in plasma glucose. This classification also reflects the impact on postprandial blood glucose homeostasis and the associated metabolic as well as endocrine responses. Table 2.5 summarizes the characteristics of SDS, RDS, and RS.

Dextrin: Dextrin is a polymer of glucose units and is a byproduct of starch hydrolysis, which can be achieved by enzymatic degradation (salivary amylase in the mouth). Also treatment with dry heat like toasting, results in breakdown of starch to dextrin. This process is called dextrinization, which produces brown color and gives a distinct aroma to the food. This generally occurs in foods containing starch, like bread or chapati. Dextrin occurs naturally in potato, corn, wheat, etc. Dextrin is sweet in taste and easy to digest. Therefore, mastication in the mouth produces sweet taste and supports digestion. Toasted bread also tastes sweet upon chewing.

Resistant dextrin is a glucose polysaccharide that is not digestible. It is formed when starch is heated and treated with enzymes. It is fermented by the colonic microflora. In overweight adults, it has been found to have beneficial effects by reducing body weight and body mass index. It is possible that it may enhance satiety, which needs to be verified by further research.

Inulin: Inulin is a polymer of fructose units, naturally found in substantial amounts in Jerusalem artichoke and chicory tuber, although it is widely present in about 3,000 plants. Inulin, which is extracted from chicory root, is an oligosaccharide. It is used as a sucrose replacer as well as fat substitute. It gives only 25–35% of the energy obtained from digestible carbohydrates. Its sweetness is only one-tenth of the sweetness of sucrose. It gives about 1.5 kcal/g. It is not digested by human small intestines and can be used as a prebiotic. Inulin has been shown to increase *Bifidobacteria* in the colon. It helps in growth of healthy bacteria and reduces toxins and carcinogens. It has been shown to reduce lipid levels, i.e., trigylcerides and cholesterol in blood. It also improves mineral absorption and activates the immune system and is useful in diabetes and weight management. It is also used in bakery products and ice-creams.

Modified starches: Starch has limited use in its native form. Therefore, its functional properties are modified by several physical and chemical methods, mainly to provide specific functional properties. The native starch that is modified and produced by various processes is called modified starch, e.g., pregelatinized starch and extruded starches. Different processes are used such as oxidation, esterification, hydroxymethylation, dextrinization, cross-linking, etc. By subjecting the native starch to the process, the stability of the starch to severe heat, shearing, freezing, etc. is improved significantly. Modified starches have a significant role in food industry for developing food products. Modified starches are used as thickeners, emulsifiers, binders, and stabilizers for bakery products and confectionery. They are polymers that are used in microencapsulation for oil-based flavors, micronutrients, fragrances, agrichemicals, and pharmaceuticals. Modified starches also have non-food applications such as in the textiles industry.

Modified starch is also used in making edible films and the functionality of films is based on the ratio of amylose to amylopectin in the starch. High amylose content produces elastic films whereas high-amylopectin starch leads to films exhibiting poor mechanical properties. Chemical modifications of starch including acetylation and oxidation may be used to improve edible films properties.

Table 2.5: Characteristics of the three types of starch.

Rapidly digestible starch (RDS)	Slowly digestible starch (SDS)	Resistant starch (RS)
• Present in freshly cooked starchy foods • Rapidly digested • Absorbed in the duodenum and proximal regions of the small intestine leading to a rapid elevation of blood glucose and usually a subsequent episode of hypoglycemia. • Glucose is released within 20 minutes after digestion • These rapid and large increase in blood glucose levels can further lead to cell, tissue, and organ damage • *Sources:* Cooked starchy cereals or cooked potato still warm.	• Present in most raw cereals, legumes, and pasta • Digested slowly throughout the small intestine to provide sustained glucose release with a low initial glycemia and subsequently a slow and prolonged release of glucose, leading to prolonged energy availability, compared with more rapidly digestible starch • Glucose is released between 20 minutes and 120 minutes after digestion • *Sources:* Raw cereals, pasta, and legumes.	• It is not digested in the upper gastrointestinal tract, but is fermented by the colonic microflora, producing short-chain fatty acids that provides additional energy to the body along with butyrate that is beneficial to colonic health • Starch is not hydrolyzed even after 120 minutes • *Sources:* Unripened banana or plantain, partially milled cereals.

JAYPEE BROTHERS

for detailed information on nutrition books, visit our website www.jaypeebrothers.com, for detailed information on nutrition books, visit ou

Textbook of Human Nutrition

Salient Features

- A compact and complete text on the subject
- Deals with the human food choices and eating patterns as well as their impact on the health and well-being
- Provides basic information about individual nutrient of high importance along with the latest recommended dietary allowances (RDAs) and dietary guidelines
- Suggests techniques of planning for nutritionally balanced diet through food pyramid
- Transcends into nutritional and dietary considerations in infancy, childhood, adolescence, adulthood, and other special life stages such as pregnancy, lactation, and old age
- Focuses on malnutrition problems through nutritional deficiency disorders and some of the diet-related diseases such as diabetes, hypertension, obesity and osteoporosis along with national policies and programs to attain food and nutrition security
- Presents the emerging topics such as fortification, irradiation, biotechnology, functional foods, nutraceuticals, dietary supplements, pre- and probiotic, nanotechnology and nutrigenomics, and role of nutrition in sports persons, astronauts, and mountaineers
- Helpful for the students and teachers of nutrition, dietetics, nursing, health science, and medicine.

(Late) Anjana Agarwal MSc PhD has done her MSc (Foods and Nutrition) from GB Pant University of Agriculture and Technology, Pantnagar, Uttarakhand and PhD from Lady Irwin College, University of Delhi, New Delhi, India. She headed the Department of Home Science in a biomedical college at Dehradun. She was also attached with the Department of Food Science and Nutrition Consultant at the Postgraduate Studies and Research in Home Science at SNDT Women's University, Mumbai, and got involved in teaching undergraduate and postgraduate students in various academic institutions of the university. She has organized several seminars and workshops concerning nutrition. She has frequently been assigned new subjects in nutrition, be it basic nutrition, public health nutrition, food product development. Besides nutrition, her expertize includes aromatherapy in which she conducted several workshops in Mumbai. She has published some research and review articles in scientific journals and many popular articles on nutrition in health magazines.

Shobha A Udipi MSc PhD Research Director and Head, Hon Director, Integrative Nutrition and Ayurceuticals Kasturba Health Society-Medical Research Centre, Mumbai, Maharashtra, India; Professor Emeritus, Transdisciplinary University of Health Sciences and Technology, Bengaluru; Former Professor and Head, Department of Food Science and Nutrition, SNDT Women's University, Mumbai. She obtained her PhD degree in Food and Nutrition from Purdue University, USA in 1984 and her MSc from SNDT Women's University, Mumbai in 1977. She has undertaken several research projects for industry and in community sponsored by national and international agencies. She has been an expert invitee for the development of syllabus for UGC, NCERT, and IGNOU in various capacities at national level. She has published 70 research papers in national and international journals. She has also co-authored 3 books and authored the book *Food Irradiation*.

Printed in India

Available at all medical bookstores
or buy online at www.jaypeebrothers.com

JAYPEE BROTHERS
Medical Publishers (P) Ltd.
EMCA House, 23/23-B, Ansari Road,
Daryaganj, New Delhi - 110 002, INDIA
www.jaypeebrothers.com

Join us on facebook.com/JaypeeMedicalPublishers

Shelving Recommendation
NUTRITION

ISBN 978-93-89587-86-9