UNIT 1 INTRODUCTION TO FOOD SCIENCE AND SIMPLE SUGARS

Structure

1.1 INTRODUCTION

This first unit introduces the concept, scope and importance of food science and technology as a discipline. It further presents a detailed discussion on carbohydrates in the diet, their classification, functional properties and their uses in foods. The main focus of this unit is, however, on simple sugars.

Objectives

After studying this unit, you will be able to:

- appreciate the discipline of food science and the modern developments in this subject area,
- classify carbohydrates,
- discuss the functionality of sugars in our food, and
- enumerate the different sweeteners and their functions.

1.2 INTRODUCTION TO FOOD SCIENCE AS A DISCIPLINE AND MODERN DEVELOPMENTS

As an undergraduate student you may have taken a course in food science and technology. Do you recall, what did the study of food science and/or food technology entailed? In this course, we will introduce you to the concept, scope and importance of food science and technology. We begin our study by first defining what food science and technology is?

Food Science is a discipline in which the biological and physical sciences and engineering are used to study the nature of foods, the causes of their deterioration, and the principles underlying food processing. It deals with acquisition of new knowledge to elucidate the course of reactions or changes occurring in foods, whether natural or induced by handling procedures.

Food Technology, on the other hand, is application of food science to the selection, preservation, processing, packaging, distribution and use of safe, nutritious and wholesome food. It is application of the principles and facts of science, engineering, and mathematics to the processing, preservation, storage and utilization of foods.

If you look at the definitions carefully, you would realize that food science and technology are inextricably linked. Because of their inter-linkages and commonality, you would find that they are usually treated as one field of study in many Universities.

Next, let us move on, to study the importance of this discipline in general and specific to dietetics and food service management.

Paying Attention to Food Science and Technology – Subject Scope

Food science and technology has developed as a discipline to systematically organize and link various kinds of knowledge which are necessary to inform human activity in handling, processing, distribution and marketing of food. This also includes application of science and technology to the processing, preservation, packaging, distribution and utilization of foods and food products. The objective of the discipline is to develop a basic scientific understanding of foods and food processing as determined through biochemistry, chemistry, microbiology, physics and other sciences. Food science and technology is the key to the conversion of raw agricultural materials into a wide variety of properly processed and preserved foods, thus contributing to the well being, economy, standard of living and progress of humanity.

Food science, you would realize, actually draws on research and applies principles and practices from a broad spectrum of basic and applied sciences including biology (botany, bacteriology, microbiology, mycology), chemistry (biochemistry, physical, analytical, and organic chemistry), physics (rheology, thermodynamics, cryogenics, radiophysics, ultrasonics), nutrition, psychology (sensory behaviours), medicine (metabolism, toxicology, health and diseases) and economics.

Food technology applies the principles and concepts of engineering to problems of food handling and processing and studies interrelationships between the properties of materials and changing the methods of handling and manufacturing them.

Related research areas in this discipline include: biotechnology to produce new strains of plants for foods and more efficient manufacture of food components, molecular and structural properties of foods and how they affect the conversion, processing, distribution, storage and acceptance of foods, biosensors to monitor food operations, and development of robot technology in food manufacturing.

As you can see from our discussion above, the study of food science and technology can be quite vast and pervasive. However, the following specific topics may comprise various components of food science and technology courses. The areas covered within each of these components are highlighted herewith.

1) *Food analysis and chemistry*

Investigation of the basic composition and physical, organic and biochemical properties of food constituents at the molecular level, the changes that food constituents undergo during processing and storage. These areas also involve changes in texture, colour, flavour and determination of the effects of processing on the nutritive value of foods, techniques used by food analysts for proteins, carbohydrates, lipids, fats and oils, colloids, enzymes, vitamins, emulsifiers, acids, oxidants, antioxidants, pigments and flavours, secondary plant metabolites in food.

2) *Food quality factors and their measurement*

Within this broad component, the areas covered include: appearance, textural, flavour, nutritional, sanitary and keeping factors; quality standards, objective and organoleptic evaluation techniques and programmes; consumer acceptance; taste panels; complex changes in the physical and chemical structure of the food as influenced by several intrinsic and extrinsic factors.

3) *Nutritive aspects of food constituents and effect of processing and handling*

This component involves a study on nutrient stability; effects on nutrients of agricultural practices, handling, processing and storage of raw and processed foods including effects of cultivation, harvest, cleaning, freeze preservation, heat processing, baking, extrusion, moisture removal, fermentation, food additives, ionizing radiation; effects of home preparation and commercial foodservice practices; enrichment and protein complementation of foods; improvement of nutritional quality through plant breeding and role of the government in regulating nutritional value of the food supply.

4) *Food microbiology, mycology and toxicology*

Use of yeasts, moulds and bacteria in production of foods and food ingredients; microbes in fermentation, processing and preservation; spoilage microorganisms; indicators of food borne pathogens; detection, identification and physiology of microorganisms of importance in foods; microbiological culture; monitoring, testing and sampling methods; the development of methods for prevention of spoilage of processed foods; tools of molecular biology in detection of microbes; psychotrophs, thermophiles and radiation-resistant microorganisms; biology, culture and isolation, and identification of important fungi; quantification of fungal toxins; food toxins and toxicity.

5) *Food processing and engineering*

Fundamental engineering concepts such as momentum, heat and mass-transport systems; engineering aspects of food processing plant operations and automation; unit operations in food processing, food packaging materials, methods, testing and evaluation; effects on shelf life; economics; process control, optimizing automation; waste management; energy conservation and quality control.

6) *Food product development*

Food product development is often commodity related. This type of research needs to be carried out in the pilot plants with the equipment that is usually smaller in scale than commercial equipment. Development of newer food products with the application of the knowledge of food science and technology and the evaluation of their quality (sensory and nutritional) and marketability.

7) *Commodity topics*

All aspects of food science and technology of specific commodity groups, including milk and milk products (fluid milk and derivatives, ice cream and related products, cheeses), meat, poultry and eggs, seafoods, fats, oils and related products, cereal grains, legumes, oilseeds, vegetables and fruits, beverages, confectionary and chocolate products.

8) *Food safety and regulation*

Food sanitation as related to public health and food plant processing; rules and regulations, food ingredient labelling, nutrition labelling, food law, food additives, food borne diseases, detection, identification, governmental and nongovernmental agencies concerned with food safety, current issues, such as *Salmonella* in eggs, etc.

9) *The food industry*

Publications of major trade associations, industry standards, structure of the food industry, international food corporations, information on allied industries e.g. packaging (steel, aluminium, glass, paper, plastic), chemical manufactures (acidulants, preservatives, enzymes, etc.) and food machinery and equipment manufactures. Popular or consumer works on home processing or food safety and marketing of food products and food prices.

10) *Food processing unit operations*

Food processing unit operations are involved in the engineering aspects of food processing, packaging and storage. Heating, cooling, drying, concentrating, textural measurement and separation are all processes that are often used during the processing of food products and can be related to engineering principles.

In addition to the areas discussed above, few emerging trends and developments specific to this subject area are highlighted next.

Emerging trends in the area of food science/technology

Increased concern about the nutritional content of technologically derived, refined foods is expressed by both consumers and nutritionists. Dietary guidelines and nutrition education, focus on partially replacing refined foods with whole grains, legumes and other foods, which retain their biochemical integrity. Concern about food safety issues is very strong. Food scientists are responding to these nutritional and safety concerns in a variety of ways, including increased attention to food interactions and bioavailability of nutrients, improved analytical and detection methods, and research and education in food safety. New product development, particularly in the area of reduced-fat and reduced-calorie products is predicted. New processing technologies such as high energy electric pulse processing, freeze concentration and hydrostatic pressure processing show promise. Also, food biotechnology is a growing area i.e. genetically modified food (GM food).

So, now you can understand and appreciate what the study of food science and technology entails. Here, in this Course entitled Principles of Food Science, you will find a comprehensive coverage of the various components highlighted above. Some of the components have been included in the Food Microbiology and Safety Course. Therefore, we recommend that you plan your study in such a manner that both the courses are read side by side. This will help you get a comprehensive understanding on various components of this discipline.

Check Your Progress Exercise 1

1) What does the study of food science and food technology entail?

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2) Mention any two important emerging areas in food science and technology.

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1.3 CARBOHYDRATES IN THE DIET – CLASSIFICATION

There is more carbohydrate (CHO) material than all other organic material in nature. This is due to the fact that carbohydrates make up most of the organic structure of all plants, as well as, being present to some extent in all animals. In biological systems, they perform a variety of functions, about which you may have already learnt in the Advance Nutrition Course, Unit 3, including their role as structural constituents.

Carbohydrates are made up of carbon, hydrogen and oxygen, however, other elements like nitrogen, sulphur and sometimes even phosphorus may also be present in carbohydrates. Commonly, but not always, the hydrogen and oxygen in the carbohydrates are present in 2:1 ratio as in water, from which the name carbohydrate (Carbon Hydrate) was derived.

Carbohydrates are sometimes referred as *Saccharides*, which has its origin from the Greek word *Sakchron* meaning sugar. The simplest carbohydrates are called sugars (or monosaccharides) and these may link together to form more complex carbohydrates (oligo- or poly-saccharides). You may have studied about the classification of carbohydrates in the Nutritional Biochemistry and Advance Nutrition Courses. A simple classification of carbohydrates is presented here as well in Table 1.1 for your reference.

Table 1.1: The major dietary carbohydrates

Class (Degree of Polymerization)	Sub-Group	Components
Sugars (1-2)	Monosaccharides Disaccharides	Glucose, galactose, fructose Sucrose, lactose, maltose
Oligosaccharides (3-9)	Malto-oligosaccharides Other oligosaccharides	Maltodextrins Raffinose, stachyose, fructo-oligosaccharides
Polysaccharides (>9)	Starch Non-starch polysaccharides	Amylose, amylopectin , modified starches Cellulose, hemicelluloses, pectins, hydrocolloids

Monosaccharides are the simplest carbohydrate molecules. The most commonly occurring monosaccharides in food are *glucose, fructose* and *galactose*. The formula for glucose is $C_6H_{12}O_6$. It can be represented as shown in the Figure 1.1a.

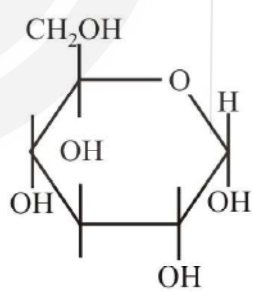

Figure 1.1(a): α-D Glucopyranose

Disaccharides are formed when two monosaccharide molecules join together with the elimination of one molecule of water. They have the general formula $C_{12}H_{22}O_{11}$. Examples of disaccharides are *sucrose* (glucose and fructose), *lactose* (glucose and galactose) and *maltose* (2 molecules of glucose). Have a look at the Figures 1.1b and 1.1c for their structures.

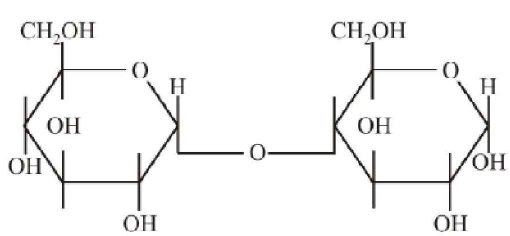

Figure 1.1 (b): Maltose (β-D Glucopyranosyl (1-4) α-D Glucopyranose)

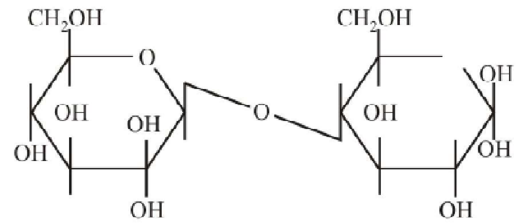

Figure 1.1 (c): Lactose (β-D Galactopyranosyl (1-4) α-D Glucopyranose)

Polysaccharides, on the other hand, are made up of many monosaccharide molecules (usually glucose), joined together. They have the general formula $(C_6H_{10}O_5)_n$ where 'n' is a large number. Examples of polysaccharides are *starch, glycogen, cellulose, beta glucan, pectin* etc.

With a basic understanding of the classification of carbohydrates, next we shall recall the sources of carbohydrates in our diet. Basically, there are two main groups of carbohydrates – *starch* and *sugars* – as you may already know. The main sources of carbohydrates in our diet include starchy foods, such as cereals, pulses and potatoes and foods and drinks containing sugars such as milk, fruits and vegetables, jam, confectionery, table sugar and some soft drinks. At an average, starches account for almost 60% of the total carbohydrate intake in the average diet and sugars form around 40%. In addition to starches and sugars, you may have studied about fibre in the context of carbohydrates. Well, *fibre* is the term given to a mixture of substances, mainly complex carbohydrates, which cannot be digested in the small intestine in humans, but pass into the large bowel where they are fermented by bacteria. Examples include *cellulose, pectin, guar gum*, *beta glucan.* Fibre is defined as *non starch polysaccharide* (NSP). The substances that make up fibre may have different actions in the body. A small amount of starch is not digested, but passes into the large intestine where it may be fermented by bacteria. This is known as *'resistant starch'* and may have properties similar to NSP.

Please note, in this unit we shall not go into the details of the structure and formula of each of these categories of the carbohydrates. We have already covered this aspect in the Nutritional Biochemistry Course. You may recall reading about the structure and properties of each of these carbohydrates in Unit 1 of the Nutritional Biochemistry Course. If you have not gone through the Nutrition Biochemistry Course, we suggest you take a break here and get your unit related to carbohydrates. Read and understand these structures and their properties carefully. An understanding of these structures/ properties is crucial for your understanding of the functionality of carbohydrates in the diet.

With the basic knowledge about carbohydrates, we are now ready to undertake a detail study on each of these groups of carbohydrates i.e. sugars, starches and non-starch polysaccharides. In this unit we shall however focus on sugars and sweeteners only. Polysaccharides i.e. starches and non-starch polysaccharides are discussed in the next unit.

1.4 SUGARS: CHEMISTRY, FUNCTIONALITY AND THEIR ROLE IN FOOD INDUSTRY

In this section we will learn about the simple carbohydrates called sugars. As you may already know, those carbohydrates that cannot be hydrolysed into simpler forms are known as *'monosaccharides'* or *simple sugars*. Monosaccharides may be made up of 3-8 carbon atoms. Chemically, these are poly hydroxy aldehydes or ketones. Depending upon the presence of aldehyde or ketone group in the structure, the carbohydrates may be aldoses or ketoses, and depending upon the number of carbon atoms present in the structure, these may be called as *pentose* (5 carbon monosaccharide) or a *ketohexose* (6 carbon monosaccharide) and depending upon the presence of aldehyde or a keto group, it may be called a *aldohexose* or *ketohexose*. A list of commonly occurring aldoses and ketoses is given Table 1.2:

Table 1.2: Commonly occuring aldoses and ketoses

	Aldoses	**Ketoses**
Trioses $C_3H_6O_3$	Glycerose or glycerladehyde	Dihydroxyacetone
Tetroses $C_4H_8O_4$	Erythrose Threose	Erythrulose
Pentoses $C_5H_{10}O_5$	Ribose Arabinose Xylose	Xyloketose
Hexose $C_6H_{12}O_6$	Glucose Mannose Galactose	Fructose
Heptoses $C_7H_{14}O_7$	Glucoheptose Galactoheptose Mannoheptose	

We will not dwell on the structure and properties of simple sugars here. Our focus in this course is to understand the functional role of these molecules in our diet. Do look up the structure and properties of carbohydrates in the Nutritional Biochemistry Course Unit 1 and in the Practical Manual. This information, we repeat, is crucial for your understanding of the functions of sugars. But, first let us look at the common sources of sugars.

Table 1.3 depicts various sugars and their common sources.

Table 1.3: Classification of sugars – sources and characteristics

Classification	**End Products on Hydrolysis**	**Source or Characteristics**
Monosaccharides *Pentoses*		
Ribose	Ribose	Derived from pentoses of fruits and nucleic acids of meat products and seafood, does not occur in free forms in foods, is an aldose
Xylose	Xylose	Is an aldose
Arabinose	Arabinose	Is an aldose
Hexoses		
Glucose	Glucose	Fruits, Honey, Corn Syrup
Fructose	Fructose	Fruits, Honey, Corn Syrup
Galactose	Galactose	Does not occur in free form in foods

Mannose	Mannose	Does not occur in free form in foods
Disaccharides		
Sucrose	Glucose	Is an aldose
	Fructose	Beet and cane sugars, molasses, maple syrup, comes in many crystal sizes and grades
Lactose	Glucose	Is an aldose
	Galactose	Milk and milk products
Maltose	Glucose	Malt products, low concentrations in plants and processed foods

Now, let us study about the functional role of sugars in food.

1.4.1 The Functional Role of Sugars in Foods

From the consumer's point of view, sugars are primarily associated with sweetness. Sweetness is essentially a physiological sensation. Thus it has to be tested by human testers – the sweetness of solutions of different concentrations is compared to that of standard sugar solutions until they appear the same. The ratio of concentrations then gives the sweetness ratio.

The most obvious role of sugar in foods is to impart sweetness, however, there are a number of other roles these play in food systems. For example, in candy making, the structural role of crystallization is usually critical. In baked products, sugar not only contributes to the browning of the product, but it may serve to tenderize the product through its action on both the gelatinization of starch and denaturation of protein. Sugars have numerous other functions as well, which make them important ingredients in many foods. They add flavour and functionality that enhances cooking, also contribute to a safe and varied food supply. Replacement of many of the functions of sugars in foods cannot be readily achieved by other ingredients. Let us get to know a little more about these functions. We start with the basic function sweetness.

1) ***Sweetness***

Sweetness is the most recognized functional property of sweeteners. Our preference for sweetness, regarded as innate, is apparent soon after birth and prior to postnatal learning and decreases with older age. Sweetness is also associated with feelings of pleasure and appreciation or reward, which contribute to the appeal of sweet foods. The combination of sugars and fats in confections provide a sweet taste and texture that compliment each other. In beverages, sucrose provides sweetness without altering the subtle flavours of the beverage. Table 1.4 shows sweetness of several common sugars relative to sucrose.

Table 1.4: Sweetness of sugars

Name	Sweetness
Fructose	1.73
Invert sugar	1.30
Sucrose	1
Glucose	0.74
Maltose	0.32
Lactose	0.16

Look at Table 1.5. It shows solubility of some of the common sugars in water.

Table 1.5: Solubility of sugars in water

Name	Solubility in grams/100 ml water
D-Fructose	Highly soluble
D-Galactose	10.3
D-Glucose anhydrous	83
Lactose	8
Lyxose	Highly soluble
Maltose	108
D-Mannose	248
Raffinose	14
Sucrose	179
D-xylose	117

2) ***Texture***

Sugars make an important contribution to the texture of foods, commonly referred to as 'mouthfeel'. For example, glucose syrups in ice-cream provide body and texture, perceived as smoothness. Adding sugar syrup helps to prevent lactose crystallization, which would cause a sandy or grainy texture associated with frozen dairy products. In candy making, controlling the rate and extent of sugar crystallization provides a vast array of different textures. These range from the soft textures of fondants and fudges, where crystallization is minimized, to hard candies where crystallization results in a desired grainy or crystalline structure. Honey has a non-crystallization property, and can therefore be used in confectioneries to maintain a soft and smooth consistency.

In bakery applications, sugars are used to impart flavour, aroma and colour. During the mixing process, excess gluten development can make doughs and batters rigid and tough. Addition of sugar will ensure that gluten maintains an optimal elasticity, allowing the dough to expand and rise properly. During mixing, flour protein is surrounded with water, forming gluten strands. The strands have thousands of balloon-like pockets that trap gases produced during leavening (a process used to produce fermentation in dough or a liquid). These gluten strands are highly elastic, and allow the batter to stretch as the gases expand. Sugars compete for water with gluten proteins, inhibiting their development and allowing proper volume and tender texture.

Sugars allow the dough to rise at an optimal rate during leavening. The naturally occurring irregular surface texture of the sugar crystals encourages yeast growth and effectiveness by providing an immediate and easily accessible source of nourishment. Under appropriate conditions, the yeast cells break down the sugar crystals, releasing carbon dioxide that causes the dough to rise. Addition of shorteners (fat/oils) to the dough allows the air to get trapped in the naturally irregular sugar crystals. As the shortening and sugar are creamed together, the trapped air cells get interspersed in the mixture. During baking, these air cells expand with carbon dioxide and other gases from the leavening agents to ensure just the right volume. The sugars naturally interact with proteins from the beaten eggs to stabilize the foam structure. This makes the egg foam more elastic, allowing it to expand as it takes up gases from the leavening process.

In bakery products, sugar is recrystallized as water is removed during baking, resulting in a crisp texture. This crispness is increased by the effects of browning (maillard reaction), which takes place when reducing sugars and nitrogen-containing ingredients (e.g. protein) are heated together. You will read about browning later in this section under the *appearance function*.

Sugars also act to tenderize bakery products by slowing the rate at which starch molecules become interlinked and proteins break down. Glucose, fructose, sucrose and maltose are used in bread making to increase dough yield and prevent excessive stickiness. While baking unshortened cakes along with sugars help ensure the cakes "set" correctly. As the temperature rises, egg proteins coagulate, or form bonds among each other. Once egg proteins coagulate, the cake "sets," forming its solid, mesh-like structure. Sugars disperse among the egg proteins and naturally interfere with the bond formations, raising the temperature at which they form.

The heat of baking causes the starch in flour to swell from moisture absorption and set in gelatinization. To create a fine, uniformly-grained cake with a soft, smooth crumb texture, the "setting" must be delayed until the optimal amounts of gases are produced by the leavening agents. Sugars are hygroscopic (capable of absorbing moisture from the air) and act to slow the gelatinization process by competing with starch for moisture. This maintains the viscosity of the batter until the optimal amount of gases are produced by the leavening agents, ensuring good texture and volume.

Surface cracking is desirable in most cookies. As sugars re-crystallize, it gives off heat that evaporates the water absorbed during mixing. This combines with leavening gases to expand and cause surface cracking of the dry surface.

We have just learnt about the textural contribution of sugars in our foods. Next, we shall focus on the preservative functions of sugars. But, first we shall take a break and attempt the exercises given under check your progress exercise 2. This will help you to assess your understanding of functionality of sugars learnt so far. Do check your responses with the answers given at the end of the unit.

Check Your Progress Exercise 2

1) Fill in the blanks:

   a) Carbohydrates are classified into ...., ... and ....

   b) Two major sources of carbohydrates in our diet are .... and ....

   c) .... is the term given to a mixture of substances which cannot be digested in small intestine.

   d) ....is undigested starch, which passes into large intestine, where it is fermented by bacteria.

   e) Honey is better than sugars in confectionery industry because of its ....property.

2) Discuss the role of sugars in:

   a) Preparation of dough and batters

   ....

   ....

   b) Formation of egg foam

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   ....

   c) Baking of cakes

   ....

   ....

   d) Surface cracking in cookies

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We now continue our study of the functional role of sugars. Let us look at the preservation role of sugars.

3) ***Preservation***

In many products, sugars play an important role in preservation. The addition of monosaccharides, such as glucose or fructose, to jams and jellies inhibits microbial growth and subsequent spoilage. Sugars have a great affinity for water, thus slowing moisture loss in foods, like baked foods and extending the shelf-life of these products. Both honey and invert sugar help to retain moisture due to their high fructose content, as do sorbitol (sucrose alcohol) and corn syrup.

Sugars are added to canned vegetables both to maintain firmness and minimize oxidation when the can is opened. Inhibiting oxidation reactions not only protects against deterioration of texture and flavour, but also the loss of colour resulting from the breakdown of pigments. The interaction between sugars and water controls the moisture in products like cakes and biscuits, to prevent drying out and staleness.

The technique of superior osmotic dehydration which is likely to provide better tasting, more nutritious, environmentally-friendly dried foods for consumers, relies on the principle of *osmosis* (movement of water and dissolved substances through the membrane to equalize this concentration difference). The principle of osmosis has been used for some time in the food industry. Food material of plant or animal origin is immersed in concentrated solutions of water, containing solutes such as sugar or salt. There is a transfer of water out of the food (dehydration) and a simultaneous transfer of solute into the food (impregnation). By controlling the extent of dehydration and impregnation, it is possible to modify the functional properties of foods. We will learn more about this aspect later in Unit 11 which focusses on methods of processing. There is a growing interest by the food industry in the process of osmotic dehydration, with the goal of extending the shelf-life while enhancing the overall quality of the final products.

Now, let us look at the role of sugars in process of fermentation.

4) ***Fermentation***

The production of chemicals by fermenting various sugars is a well-accepted science. Its use ranges from producing beverage alcohol and fuel-ethanol to making citric acid and xanthan gum for food uses. However, the high price of sugar and the relatively low cost of competing petroleum-based fuel has kept the production of chemicals mainly confined to producing ethanol from corn sugar – until now.

Ethanol has been made since ancient times by the fermentation of sugars. All beverage ethanol and more than half of industrial ethanol is still made by this process. Simple sugars are the raw material. *Zymase*, an enzyme from yeast, changes the simple sugars into ethanol and carbon dioxide. The decomposition of sugar during fermentation is identical with the reactions by which sugar begins to burn during respiration. The fermentation reaction can be represented by the following simple equation:

$$C_6H_{12}O_6 \longrightarrow 2CH_3CH_2OH + 2CO_2$$

Fermentation is actually very complex, and impure cultures of yeast produce varying amounts of other substances, including glycerin and various organic acids. We can split sucrose into glucose and fructose either by means of a strong acid, such as sulphuric acid, or by an enzyme obtained from yeast, namely *saccharase* or *invertase*. In the production of beverages, such as whisky and brandy, the impurities offer the flavour. Starches from potatoes, corn, wheat and other plants can also be used in the production of ethanol by fermentation. However, starches must first be broken down into simple sugars. An enzyme released by germinating barley, *diastase*, converts starches into sugars. Thus, the germination of barley, called *malting*, is the first step in brewing beer from starchy plants, such as corn and wheat.

Sugars, which are used to activate yeast for fermentation, are important in the brewing and baking industries. The type and the amount of sugar added to the dough in baked products can increase dough yield by influencing the rate of fermentation. Sugars, such as sucrose, glucose and fermentable corn syrups, significantly contribute to sweetness and softness in white breads. In contrast, sugars are either omitted or used in much lower amounts for hard crust breads. In these breads, yeast is activated by sugars that are formed when enzymes present in the flour act on starch.

Sugars that remain after fermentation affect flavour, contribute to the colour and texture of crusts (through non-enzymatic browning and caramelization reactions) and influence overall texture of the product.

What role does sugar have in the appearance of foods? Let us find out next.

5) ***Appearance***

The browning reactions are complex reactions which occur when foods are processed. In some, the brown flavour is highly desirable and is intimately associated in our mind with the delicacy of the product. In coffee, maple syrup, the brown crust of bread and all baked goods, potato chips, roasted nuts and many other processed foods controlled browning is necessary. Yet in other foods, browning during processing is undesirable and forms off flavour and dull appearance or even objectionable colours. In drying of fruits or vegetables and in canning or concentrating orange juice, it is highly desirable to avoid browning. The presence of carbohydrates in foods is intimately connected with the browning, which occurs. Other compounds are sometimes important but they are the ones which have some of the reactive groups of the reducing sugars and are similar to them in properties. The pigments, which are formed, are high molecular weight polymers whose constitution is difficult to determine. The browning reactions appear to be complicated not only as to the final product but also as to the course of numerous reactions. It has been exceedingly difficult to assess the chemistry of this change in the complex mixtures, which is encountered in almost every food.

Two major types of non-enzymatic browning reactions have been recognized to occur in foods during processing. These reactions include:

1) ***Maillard Reaction:*** reaction of aldehyde and ketone groups of sugars with amino compounds (mostly amino acids, peptides, proteins), independent of the presence of oxygen.
2) ***Caramelization:*** the change which occurs in polyhydroxycarbonyl compounds (sugars and sugar acids) when they are heated to high temperature independent of the presence of oxygen.

Let us learn about these reactions/changes:

a) ***Maillard Reaction:*** The Maillard reaction sometimes called non-enzymatic, non-oxidative browning is simply the reaction between the amino group of a protein or peptide or amino acid and the reducing group of a reducing sugar at high temperature. An amino group from a protein combines with an aldehyde or ketone group of a reducing sugar to produce brown colour and aroma in a variety of foods, including fried foods and baked goods such as breads. It is interesting that the type of sugar and the type of amino acids will impart the "brown" colour thus obtained. The colour may range from a yellow to red. The key here is the reducing sugar. What do we mean by reducing sugar? You may recall reading in the Nutritional Biochemistry Course that, reducing sugars store carbohydrates that react in basic solution with oxidizing agents. Those that are effective reducing sugars are fructose, glucose, maltose, galactose and lactose. Surprisingly, table sugar or sucrose, is not a reducing sugar. The reactivity of glucose on heating contributes to the subtle orange red colour in bread crust that is a result of browning (maillard reaction). Caramelization of fructose produces a dark brown crust. Breads that contain sucrose often yield a darker, rich-coloured crust than breads prepared with glucose.

b) ***Caramelization:*** Caramelization results from the action of heat on sugars at about 175ºC. At high temperatures, sugars dehydrate, break down and polymerize into viscous caramels, the chemical changes associated with melting sugars result in a deep brown amber colour and new flavours. Examples are the browning of bread when toasted in which, caramelization takes place under the oven heat, and the sugar adds a golden-brown, flavourful and slightly crisp surface that tastes great and helps retain moisture in the product or the darkening of maple sap when heated to make maple syrup. The caramelization reaction is attributed to a range of browning reactions and flavour developments. Once the melting point has been obtained, sugars will caramelize. Each sugar has its own caramelization temperature. Galactose, sucrose and glucose all caramelize, around 160°C, but fructose caramelizes at 110°C and maltose caramelizes at about 180°C. Caramel has a pungent taste, is often bitter, is much less sweet than the original sugar from which it is produced, is noncrystalline, and is soluble in water. Both extent and rate of the caramelization reaction are influenced by the type of sugar being heated.

The brown pigments formed are called as *'melanins'* or *'melanoids'* which are unsaturated polymers. In both cases a carbonyl or polycarbonyl compound is required. When a food is extracted to remove the carbonyl compounds, browning is retarded or eliminated. The plan showing the various steps of non-enzymatic browning is presented in Figure 1.2.

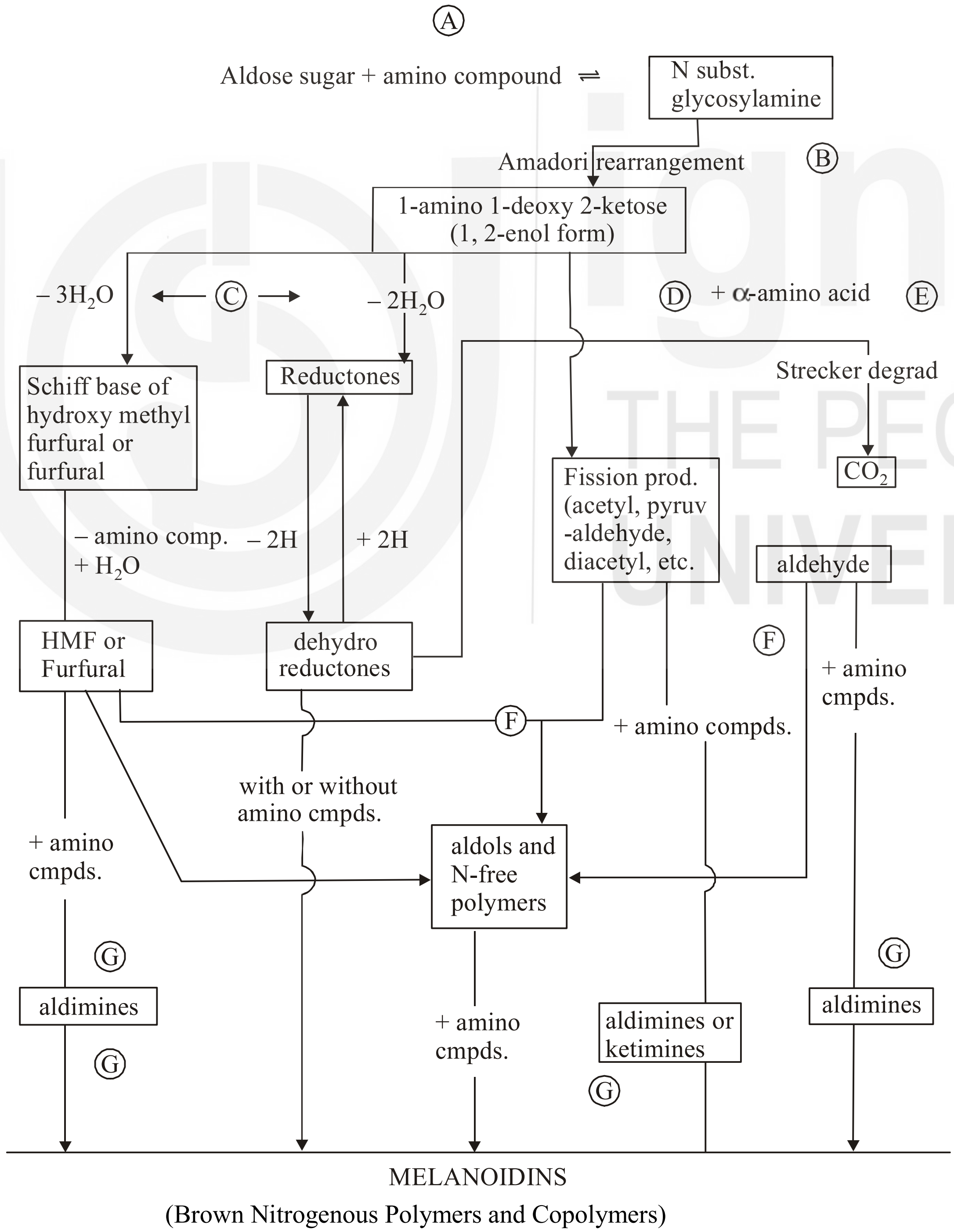

Figure 1.2: Plan showing various steps of non-enzymatic browning

It is obvious from Figure 1.2, that browning may occur by compounds entering at any point. In the first reaction, aldoses and ketoses react with amines and the reaction is known as *amadori reaction*.

The product of the reaction can undergo number of fates depending upon the conditions of the reactions as can be seen in Figure 1.2. It can, in neutral or acidic media, lose water and form a ring compound of the Schiff's base of hydroxymethyl furfural (HMF), or furfural and then eliminate the amine to form the free hydroxy methyl furfural or furfural. In the dry state, it can form reductones which have high reduction potential. Or, finally, the product can undergo fission to form small molecules such as acetol (CH_3COCH_2OH), pyruvaldehyde (CH_3COCHO), diacetyl ($CH_3COCOCH_3$) and others. In the Figure 1.2, it is obvious that all of those compounds react with amines to form aldimines or ketimines or polymerize to aldols and similar large molecules, which subsequently react with amines. The final brown pigments are produced that contain nitrogen.

The second browning reaction is *caramelization*. Sugars will show caramelization when heated at relatively high temperatures. This type of reaction is markedly affected by high pH. While the browning of these carbohydrates is not as rapid as in the presence of amino compounds, it is accelerated in the presence of carboxylic acid, salts of these acids, phosphates and metal ions. These accelerators are commonly present in foods. The nitrogen free intermediates formed in carbonyl amino browning reactions are also produced in non amino browning. The formation of 1,2 enolization, furfural and hydroxymethyl furfural by dehydration and sugar fission products has been demonstrated in some of the model systems. It has also been shown that these intermediates will form coloured polymers in the absence of amino compounds. Thus this fits well in the above Figure 1.2 after amadori rearrangement forming different nitrogen free polymers.

We hope having gone through the non-enzymatic browning reactions discussed above, you would have got a deep insight on the role of sugars in browning reactions. Next, let us look at few other functions of sugar in food.

6) ***Freezing Point***

Sugars are effective in lowering the freezing point of a solution, which is important in manufacturing frozen desserts and ice-cream products. Monosaccharides and corn syrups, containing a high proportion of low molecular weight sugars are most effective at lowering the freezing point. This property ensures smaller ice-crystals and greater smoothness of the product. The use of corn syrup sweeteners in sherbets also helps to prevent crystallization of sugars and promotes a smoother product.

7) ***Antioxidant Activity***

Many carbohydrates are excellent scavengers for metal ions. Glucose, fructose and sugar alcohols (sorbitol and mannitol) have the ability to block the reactive sites of ions, such as copper, iron and to a lesser extent, cobalt. This is characteristic of monosaccharides and aids in food preservation by retarding catalytic oxidation reactions. Furthermore, maillard reaction products are known to have antioxidant properties in food systems. For this reason, some mixtures of maillard reaction products have been employed in the food industry as food additives for biscuits, cookies and sausages.

8) ***Miscellaneous Applications***

Sugars are used in custards, puddings, pie fillings and meringues depending on the sugar to perform vital chemical and physical functions. These functions are highlighted, herewith:

a) *Custards*

While flour protein forms the structure of baked goods, custards are composed of egg protein structures. If the egg white solidifies too soon during cooking, the liquid ingredients form droplets in a process known as "syneresis" or "weeping." Sugars delay the coagulation of egg proteins and break up clumps of protein molecules, so they finely disperse in the liquid mixture and provide a smooth and stable consistency.

b) *Puddings, Sauces and Pie Fillings*

When dry starch is added directly to a hot liquid, the particles on the outside tend to cook first, lumping the raw starch particles. The lumps are unpalatable and prevent proper thickening. Adding sugars to starches before the hot liquid ensures the starch particles disperse evenly into the mixture.

c) *Meringues*

Egg whites beaten for a meringue hold air bubbles because the mechanical action of the beaters partially coagulates the egg protein. Sugars make the protein structure more adhesive and increase its ability to hold air bubbles, resulting in a stiffer, higher and more stable foam.

d) *Icings*

Sugars provide sweetness, flavour, bulk and structure to icings and frostings. In addition to sweetness and flavour, icings also function as a barrier to moisture, extending the freshness.

e) *Frozen Dessert Applications*

Sugars enhance the creamy texture and pleasing taste of frozen desserts such as ice cream, ice milk, frozen custard and sherbet.

Reducing sugars, such as glucose, fructose, maltose and lactose are recommended for ice cream. Somewhat higher proportions are used for lower fat desserts, such as ice milk and sherbet, in order to counterbalance the reduced amount of butter-fat. When cream is replaced with lower fat ingredients, such as milk or fruit puree, additional amounts of sugars are necessary to ensure a smooth, creamy mouthfeel and balanced flavour.

Apart from the functions discussed above, sugars also enhance flavours and impart mouthfeel to food products. Let us see how.

Flavours and Mouthfeel: In frozen desserts, sugars balance flavour and mouthfeel. Since low temperatures tend to numb the taste buds, sugars enhance flavours, thereby eliminating the need for additional flavour ingredients. They also increase viscosity (thickness), imparting a thick and creamy mouthfeel.

Check Your Progress Exercise 3

1) State whether the following statements are true or false. Correct the false statement.

   a) Addition of sugars to jams and jellies slows down the moisture loss, which extends their shelf life.

   ....

   b) Maillard reaction and caramelization involve the reaction of reducing group of sugar and amine.

   ....

c) In Amadori reaction, aldoses and ketoses react with carboxyl group.

....

d) The presence of an acid does not have an affect on the process of caramelization.

....

2) Fill in the blanks:

a) Sugars are added to canned vegetables to maintain .... and minimize ....

b) The principle of .... involves movement of water and dissolved substances through the membrane.

c) Sucrose can be split into its constituents by the action of ……….............. or ....

d) The dark pigments produced by maillard reaction are termed as ....

e) Sugars are important constituents of frozen desserts as they balance ....and.. .

3) Explain the following in 1-2 lines:

a) Maillard Reaction

....

b) Caramelization

....

c) Weeping

....

d) Amadori Reaction

....

Having learnt about sugars and there applications in food industry, we move to the next group of simple sugars i.e. Sweeteners.

1.5 SWEETENERS

As a group, artificial sweeteners are classed as "non-nutritive". Thus, they provide sweet sensation to the tastebuds, without raising blood sugar levels or insulin, and are useful for weight-loss because they are calorie and carbohydrate-free.

Artificial sweeteners, like saccharin, nutrasweet (aspartame) and the cyclamates, provide sugar-like taste and they are far sweeter than the sugars themselves. Small amounts of these synthetic chemicals can replace sugars. Artificial sweeteners provide taste properties for those who wish to reduce calories, or those with illnesses like diabetes whose body cannot tolerate sugars. The artificial sweetener, saccharine, was discovered accidentally in the 19^{th} century. A chemist tasted sweetness on his hands and his observation led to the identification of a particular chemical 500 times sweeter than sugar, which has served as a substitute for sugar for more than 100 years. The chemicals shown in Figure 1.3 are all artificial sweeteners i.e. sugar substitutes.

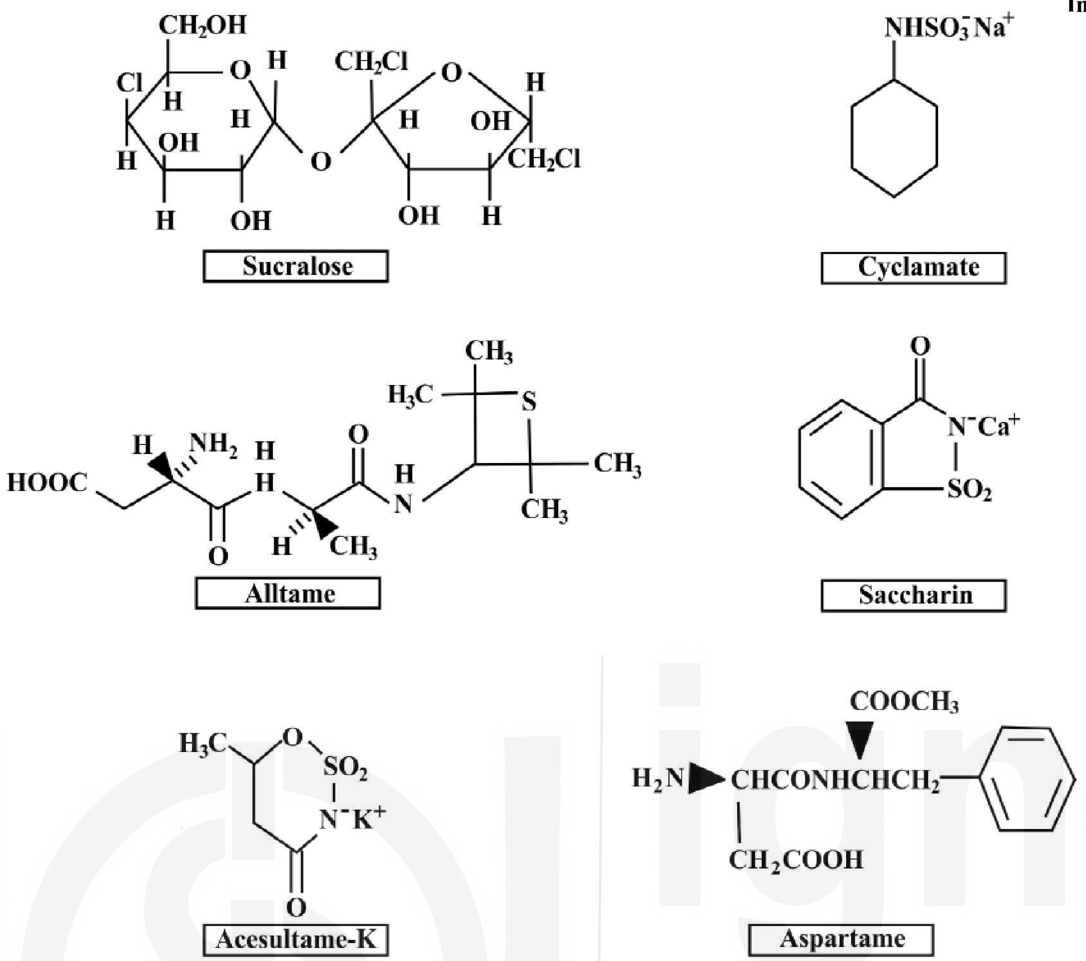

Figure 1.3: Artificial sweeteners

Some of these are available as tablets, as sugar substitute and others appear as ingredients in many food products, not just in 'diet' foods. Out of the compounds shown, aspartame finds maximum use in the food and other products. The chemical name for aspartame is N-L-*α-aspartyl-L-phenylalanine 1-methyl ester*, thus the name *aspartame* was extracted. In 1965, *James Schlatter*, of the G.D. Searle pharmaceutical company, inadvertently *tasted an experimental compound* that he had synthesized in an attempt to discover a better gastric hormone inhibitor, an ulcer drug. This unexpected and fortunate event (for, as we all know, we are instructed to limit exposure to chemicals with unknown properties) led to the development, approval, marketing and acceptance of the most widely used "artificial" sweetener in the world called 'aspartame' more commonly known by its trademark name, *NutraSweet*. However, one of the drawbacks of aspartame is its instability to heat and acid. Some interesting concepts/critical points related to aspartame are highlighted in the aspartame concept presented in Figure 1.4.

Acesulfame-K (potassium salt of 6-methyl-1, 2, 3-oxathazin-4(3H)-one 2, 2 dioxide) is a sweetener which is commonly used in dry mixes, table uses and chewing gum. It is 200 times as sweet as sugar and it is not metabolized and is thus non-caloric. Food products often contain a mixture of sweeteners. This is because it has been found that they have a synergistic effect whereby the sweetness of a mixture is greater than that of the individual components. This means that less amount can be used to get the same apparent sweetness.

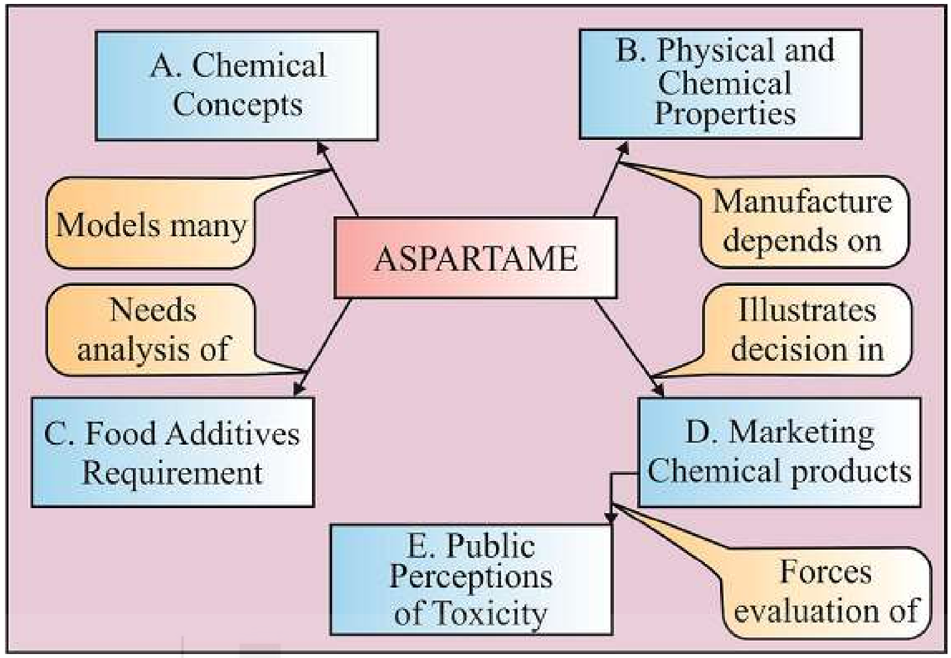

Figure 1.4: Aspartame concept

Sucralose (1,6-dichloro-1,6-dideoxy-β-D-fructofuranosyl-4-chloro-4-deoxy-α-D-galactopyranoside) is the only non-nutritive sweetener based on sucrose. Its structure is shown in the Figure 1.3 for your better understanding. It is selectively chlorinated and the glycosidic link between the two rings is resistant to hydrolysis by acid or enzymes thus, it is not metabolized. It is 400-800 times sweeter than sucrose. It is highly soluble in water and is stable to heat.

Alitame (L-α-aspartyl-N-(2,2,4,4-tetramethyl-3-thietanyl)-D-alaninamide), as illustrated in Figure 1.3, is a sweetener based on an amino acid, like aspartame. It is 2000 times as sweet as sugar and although it is metabolized, very little is needed and it is non-caloric (1 g can replace 2 kg of sucrose). Alitame has a 'sweet and clean taste'.

The oldest artificial sweetener is *saccharin* (the calcium or sodium salt of 1,2-benzisothiazol-3(2H)-one 1, 1-dioxide) as shown in the Figure 1.3, is used for over a century. It is 300 times as sweet as sucrose, but many people don't like its bitter aftertaste. It is also controversial as some animal studies showed that massive doses of saccharin produced cancer. However, it was not banned as the evidence of harm to humans wasn't there and the levels fed to rats were so high for its carcinogenic effect. It is widely used in a variety of products and the health risk, compared to the risk of over-consumption of sucrose, appear to be much lesser.

Another sweetener is *cyclamate* (sodium cyclohexylsulphamate). Have a look at its structure as shown in the Figure 1.3. It is only 30 times as sweet as sucrose, which does not give it a strong competitive advantage.

Several minor sweeteners are under evaluation which were derived from natural sources. For e.g. *stevioside* from a South American plant, glycyrrhizin from licorice root, *thaumatin*, a mixture of proteins from a West African fruit.

The most interesting potential sweetener from a chemical point-of-view is left-handed Sucrose. It is also called *invert sugar*. Let us learn about this natural sweetener.

Invert Sugar

Invert sugar is sucrose, which can be hydrolyzed to split the disaccharide into its component sugars, fructose and glucose. It is called invert sugar because hydrolysis of sucrose causes the solution to alter the rotation of polarized light, an effect known as the *inversion of sucrose*. This inversion takes place due to the presence of either enzyme or acid. The fructose and glucose combination is much more soluble than the sucrose crystals and so the consumer perceives syrup that is very sweet.

High Fructose Corn Syrup (HFCS) is manufactured from corn starch. The corn starch is hydrolyzed by acid or enzyme and then the resulting glucose is “inverted” into fructose. The percentage of inversion can be changed by altering the processing conditions. This is another processing method in foods, particularly in the sweetener area.

In food systems, acid and enzymes hydrolyze and invert the sugars into their component monosaccharides. The implications of this are that, any product, which has an acid compound, may bring about the hydrolysis of sucrose into fructose and glucose. This is particularly important, if the product is heated. Fructose and glucose being reducing sugars (whereas sucrose is not), enhance browning. They are more soluble and more hygroscopic than sucrose. Crystallization of sugar can be a problem, in a variety of products. For example, in the candy industry.

Table 1.6 depicts the relative sweetness of the various sweeteners. It is the standard to compare the sweetness of a product to sucrose. Sucrose is 100 and is the standard for comparison.

Table 1.6: Sugars and sweeteners

Sugars and sweetners	**Rating**
Fructose	140
HFCS	120-160
Sucrose	100
Glucose	70-80
Corn syrup	70-75
Regular corn syrup	50
Maltose	30-50
Galactose	32
Lactose	20
High conversion corn syrup	65
Regular conversion corn syrup	50
HFCS-90%	120-160
HFCS-55%	>100
HFCS-42%	100
Invert Sugar	50
Sorbitol	50
Xylitol	100
Saccharin	30,000-50,000
Sucrol [Dulcin]	20,000
Honey	97
Molasses	74
Sorghum Syrup	69
Corn Syrup	30
Aspartame	180x
Sucralose	600x
Saccharin	300x

Well then, we have a wide range of sweeteners to choose from. Which sweetener to select? Is aspartame better or saccharine? Very often we are confronted by such issues.The bottom line is to look for the following considerations while selecting a sweetener:

- the desired taste profile of the food
- the interaction between sugars and/or sweeteners
- the interaction between sugars and sweeteners and other ingredients, and
- the cost of sugars/sweeteners.

Check Your Progress Exercise 4

1) What are sweeteners? List the common sweeteners available in the market.

....

....

2) What points would you keep in mind while selecting a sweetener?

....

....

3) What is an invert sugar? Give an example of invert sugar.

....

....

4) Arrange the following sweeteners in increasing orders of sweetness.

Glucose, Sucrose, Invert sugar, Fructose, Saccharin, Honey, Aspartame

....

....

1.6 LET US SUM UP

Food science and technology are so inextricably linked that usually these are treated as one field of study. In this unit we learnt that while food science deals with the study of the nature of foods, the causes of their deterioration and the principles underlying food processing, food technology is the application of food science to the selection, preservation, processing, packaging, distribution and use of safe, nutritious, and wholesome food. It is the application of the principles and facts of science, engineering, and mathematics to the processing, preservation, storage, and utilization of foods with the final aim of delivery of safe, nutritious and cost effective food to the customer.

The simplest carbohydrates are called sugars (or monosaccharides). In this unit we studied about the major use of sugars in the food industry that is to provide the sweetness in different products. Apart from that, the sugars have a number of other functions in the food systems. An important function of the sugars is their involvement in the process known as *non-enzymatic browning*, which is desirable in various food products, especially in bakery products, but undesirable in other. However, in the patients, who are not able to metabolize sugars (particularly diabetics), various sugar replacers, also known as artificial sweeteners, are available (with low to no calorific value). The major player of artificial sweetener is aspartame.

1.7 GLOSSARY

Biosensors : a device that uses biological materials to monitor the presence of various chemicals in a substance.

Caramelization : formation of dark coloured complexes when sugars are heated at high temperature.

Complex Carbohydrates : also known as Polysaccharides. Made up of many monosaccharide units joined together in a linear or branched fashion.

Invert sugar : hydrolyzed sugar to produce the constituents ie., glucose and fructose.

Modified starches : modification of starch structure by physical / chemical means to attain a particular functional property(ies).

Monosaccharides : simplest form of carbohydrates which cannot be hydrolyzed further into smaller units.

Reducing sugar : sugars with free aldehyde or ketone group, capable of reducing cupric to cuprous form in alkaline medium.

1.8 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1) Food Science is a discipline in which the biological and physical sciences and engineering are used to study the nature of foods, the causes of their deterioration, and the principles underlying food processing. It deals with acquisition of new knowledge to elucidate the course of reactions or changes occurring in foods, whether natural or induced by handling procedures. Food Technology is application of food scinece to the selection, preservation, processing, packaging, distribution and use of safe, nutritious and wholesome food. It is application of the principles and facts of science, engineering and mathematics to the processing, preservation, storage and utilization of foods.

2) The emerging areas in Food Science and Technology are: (any two of the following):

   - Food safety
   - High energy electric pulse processing
   - Freeze concentration
   - Hydrostatic pressure processing

Check Your Progress Exercise 2

1) a) monosaccharides, disaccharides, polysaccharides

   b) starches, sugars

   c) Fibre

   b) Resistant starch

   e) non-crystallization

2) a) Addition of sugar ensures that gluten maintains an optimal elasticity allowing the dough to rise and expand properly.

   b) Sugars interact with proteins from the beaten eggs to stabilize the foam structure, making it more elastic.

   c) In cakes, the egg proteins coagulate to form a mesh-like structures. Sugars disperse among the egg proteins and raise the temperature at which they form. They also slow gelatinization process by competing with starch for moisture, which maintains viscosity of batter and ensures good texture and volume.

d) Re-crystallization of sugars gives off heat that evaporates the water absorbed during mixing. This combines with leavening gases to expand and cause surface cracking of the dry surface of cookies.

Check Your Progress Exercise 3

1) a) True

b) False. Caramelization is the change in sugar and sugar acids.

c) True

d) False. The presence of an acid accelerates the process of caramelization.

2) a) firmness, oxidation

b) osmosis

c) H_2SO_4 or zymase

d) melanins

e) flavour, mouthfeel.

3) a) Reaction of aldehyde and ketone compounds with amine groups, mostly amino acids, peptides and proteins at a high temperature is referred to as Maillard reaction. It is also called as non-enzymatic, non-oxidative browning.

b) Caramelization is the change which occurs in polyhydroxycarbonyl compounds when heated to high temperatures at about 175°C.

c) The early solidification of egg-whites resulting in the formation of droplets of the liquid ingredients is referred to as weeping.

d) Amadori reaction is the reaction of aldoses and ketoses with amines.

Check Your Progress Exercise 4

1) Sweeteners provide sweet sensation to the taste buds, without raising blood sugar levels or insulin. The common sweeteners available in the market are sucralose, cyclamates, alitame, saccharin, acesulfame-k and aspartame.

2) The points that must be kept in mind while selecting a sweetener are the desired taste profile of the food, the interaction between sugars and/or sweeteners, the interaction between sugars and sweeteners and other ingredients and the cost of sugars/sweetners.

3) Invert sugar is a mixture of equal parts of glucose and fructose resulting from the hydrolysis of sucrose. Sucrose is invert sugar.

4) Invert sugar, honey, glucose, sucrose, fructose, aspartame, saccharin.