UNIT 6 CARBOHYDRATES

Structure

6.0 OBJECTIVES

After studying this Unit, we shall be able to:

- identify foods containing carbohydrates;
- classify carbohydrates on the basis of their structure;
- explain the physical and chemical properties of carbohydrates;
- describe the nutritional and clinical significance of carbohydrates; and
- outline the applications of carbohydrates in food.

6.1 INTRODUCTION

Carbohydrates are probably the most familiar food components. They are important energy sources and are well known for their nutritive value. Carbohydrates are the products of photosynthetic process that takes place in green plants by the reaction of carbon dioxide and water in the presence of sunlight. They are present in almost all types of foods. Some of these may be simple molecules like the sugars which are water soluble. Others are complex and large molecules like starch, cellulose etc. which do not dissolve easily in water. Sugars are used as sweetening agents, humectants, as coloring agents (enzymatic and non enzymatic browning), as dehydrating agents and as fillers/ ingredients in food processing. Carbohydrates can also be used to modify the

flow behaviour, melting point of food like soups, juices. They can be used as fillers and bulking agents. Some of the carbohydrates are associated with other biomolecules like the proteins and lipids etc. to form glycoproteins and glycolipids respectively which play important role in biological systems.

We have read in the previous Unit that the water activity of a food depends on its interaction with the constituents of food. The carbohydrates in food provide room for a number of such interactions through hydrogen bonding. The carbohydrates undergo various physiochemical changes during the processing and preservation of foods and affect the food quality. The processing and preservation phenomena can be well understood if their structure and behaviour are known.

Keeping in view the significance of carbohydrates in food industry, this Unit deals with their occurrence, classification, properties, nutritional and clinical importance. The Unit also discusses their importance in food industry. The next Unit deals with another important food component i.e. proteins and enzymes.

6.2 OCCURRENCE

As mentioned above, carbohydrates are widely distributed in all the living organisms. These are important components of plant tissues, animal tissues and some of the microorganisms which produce them in the form of gums. You must have studied that in plants, carbohydrates are distributed in two forms: (1) starch (in stored forms) and (2) cellulose (in structural parts). And simple sugars like glucose and fructose are present in fruits. Sucrose, the sugar used in every household is obtained from sugarcane and sugarbeet. The amount of carbohydrates in animals is much less as compared to that in plants. These are present primarily in the form of glucose and glycogen. Glycogen is the storage carbohydrate in animals. Probably you know that lactose is a type of carbohydrate also called the milk sugar present in milk,. Some examples of the carbohydrates secreted by many microorganisms include xanthan gum, gellan gum, pullulan, etc. Table 6.1 lists some of the common foods and the percentage of different types of carbohydrates found in them. However, you will be able to appreciate the various types of carbohydrates only after studying about these in the coming sections.

The plants have carbohydrate component from 60 to 90% of their dry mass where as in animals it is less than 1%.

Table 6.1: Composition of Carbohydrates in Some Foods

S.No.	Food Product	Carbohydrate (%)				
		Glucose	Fructose	Sucrose	Starch	Cellulose
1.	Wheat	0.1	0.1	1.0	71.0	-
2.	Rice	-	-	-	79.0	-
3.	Meat	0.01	-	-	-	-
4.	Beans	-	-	3.0	10.0	-
5.	Groundnut	-	-	4.5	15.0	-
6.	Apple	1.17	6.04	3.78	1.5	1.0
7.	Orange	2.5	1.5	4.6	-	-
8.	Grapes	5.35	5.33	1.32	-	0.6
9.	Potato	0.1	0.1	-	20	0.5
10.	Tomato	1.2	1.6	1.0	-	-
11.	Sweet corn	-	-	12-17	-	0.7

Carbohydrates were initially given trivial names on the basis of their source. There was no correlation with the chemical structure in these names and some of them are still used. The suffix '*ose*' was used with the prefix of the source name. Thus fructose meant fruit sugar, maltose: malt sugar, lactose: milk sugar, xylose: wood sugar, sucrose: cane sugar and so on. We shall see how these are named on the basis of their structure in the next section.

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1) Sucrose is the same as table sugar. Which of the following will be the best sources of sucrose? Tick mark (√) the right choice.

i) Orange juice
ii) Milk
iii) Pulses
iv) Sweet corn

6.3 STRUCTURE AND CLASSIFICATION

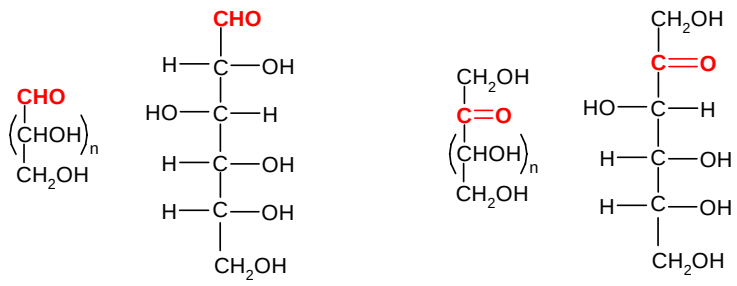
Carbohydrates are a class of organic compounds containing carbon, hydrogen and oxygen and have a general formula $C_x(H_2O)_y$ where x and y are whole numbers. Due to this formula they were once considered to represent hydrated carbon or **hydrates of carbon**. This meaning fits well with the name **carbohydrates** (*carbon hydrates*). However, it was realised later that there was no water molecule in the molecular formula of a carbohydrate. Accordingly, a new name *viz*. **saccharide** (derived from ***sakchron*** meaning sugar) was proposed for these. We continue to use the familiar term carbohydrate though it is not quite apt.

Let us look into the actual structure of carbohydrates.

6.3.1 Structure of Carbohydrates

Aldehyde: RCHO
Ketone: R_1R_2CO

The arrangement of atoms in carbohydrates in their simple linear form contains a chain of carbon atoms in which except one, all the carbon atoms carry one OH group each. One carbon atom carries a carbonyl group(C=O). The carbonyl group may be located at the end of the carbon chain as an **aldehyde** or inside the chain as a **ketone**. This chain can have three to hundred of carbon atoms. On the basis of this arrangement of atoms and groups, carbohydrates are defined as '**polyhydroxyaldehydes** or **ketones** or **the substances which give aldehydes or ketones on breakdown**'. Glucose, the most common simple carbohydrate, is a polyhydroxyaldehyde while fructose is a polyhydroxyketone**.** The general linear structures of simple carbohydrates along with an example each are represented in Fig. 6.1.



General structure **Glucose** **General structure** **Fructose**

Fig. 6.1: Structures of (a) polyhydroxyaldehydes, and (b) polyhydroxyketones

The linear structure of glucose shown in Fig.6.1 could explain many of its properties but could not account for certain significant observations. Notable among them being its existence in two different crystalline forms. These are obtained by crystallisation from concentrated solution of glucose at different temperatures. The two forms have different melting points also. This fact could be explained by proposing a cyclic structure for glucose. This structure is obtained when one of the — OH groups in the open chain reacts with the — CHO group to form **a cyclic hemiacetal** structure. In this structure, glucose forms a six-membered ring in which — OH at C-5 is involved in ring formation. These two cyclic forms exist in equilibrium with the open chain structure as shown in Fig. 6.2. The phenomenon related to the existence of these two forms is called **mutarotation** and is explained in Section 6.4.

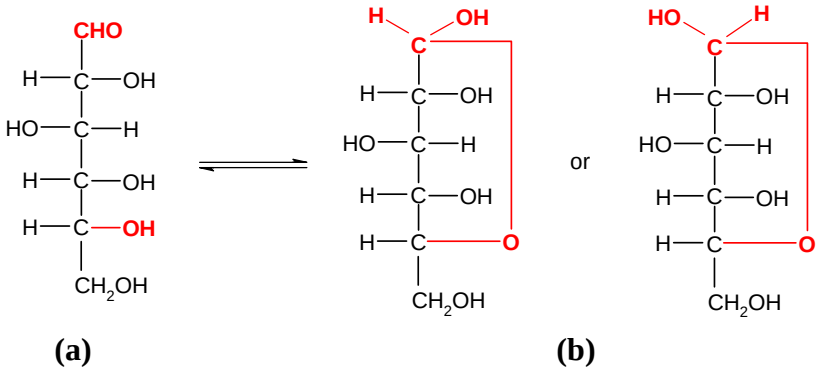


Fig. 6.2: (a) Open chain, and (b) Cyclic hemiacetal structures of glucose

As can be seen in Fig. 6.2 the two forms have different stereochemistry at the first carbon atom. These are generally represented as pyranose structures given Fig. 6.3. As you can see, these are six membered cyclic structures with an oxygen atom in the ring. The OH group at C -1 can be either below or above the plane of the ring. These two positions give rise to **α** and **β forms** respectively of cyclic glucose.

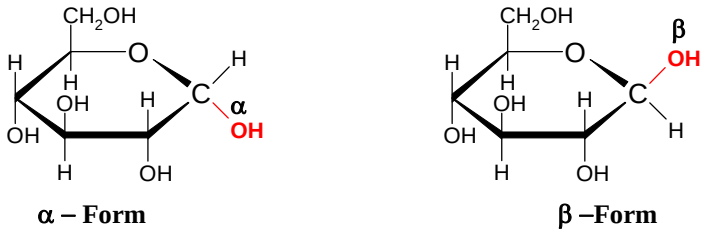


Fig. 6.3: Pyranose structures of glucose

Check Your Progress Exercise 2

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1) You have read above that glucose on cyclization gives a six membered cyclic structure called pyranose. Make a guess of what will be the size of the ring when fructose gets cyclized.

……

……

……

6.3.2 Classification of Carbohydrates

Carbohydrates can be classified in several ways. The classification may be on the basis of their chemical structures, composition, nature of carbonyl function, reaction with oxidising agents or physiological roles. According to the Food and Agriculture Organization and the World Health Organization, the carbohydrates should be classified primarily by molecular size. Accordingly, the carbohydrates are classified into sugars, oligosaccharides, polysaccharides and polyols. Each group can be further divided into various sub-groups. We however would not go into these details here and be content with a broad classification. These are explained as given below.

Sugars

Sugars are also called simple carbohydrates and consist of **monosaccharides** and **disaccharides.** The monosaccharides consist of a single polyhydoxyaldehyde or ketone unit that cannot be hydrolysed into smaller such units. Glucose and fructose are the common examples of monosaccharides. Fructose or the fruit sugar is sweetest of all sugars. These two monosaccharides are present in varying amounts in honey, maple syrup, fruits, and vegetables and in some processed foods.

Monosaccharides can have three, four, five, six or seven carbon atoms in them and are called **trioses, tetroses, pentoses, hexoses** and **heptoses** respectively. The structures of some monosaccharides with different number of carbon atoms are given in Fig. 6.4.

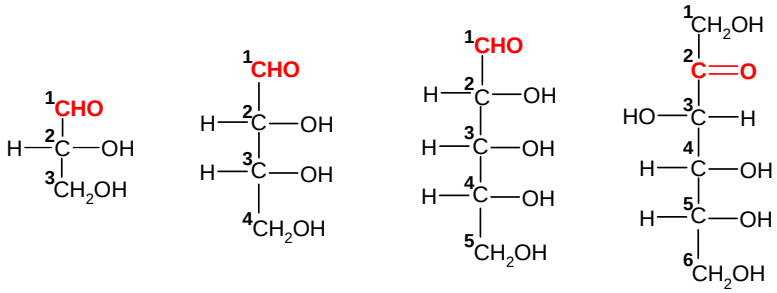
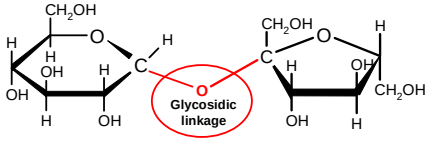


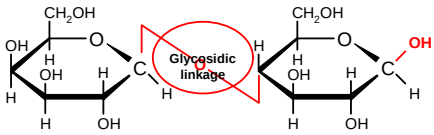
Fig. 6.4: Structures of some monosaccharides with different number of carbon atoms

Sucrose = Glucose + Fructose
Lactose = Galactose + Glucose
Maltose = Glucose + Glucose

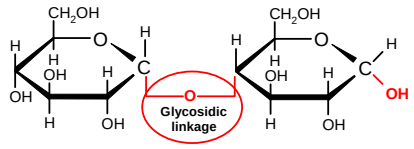
The **disaccharides** consist of two molecules of monosaccharide units joined by **glycosidic** bonds. Sucrose or cane sugar, lactose or the milk sugar and maltose, the malt sugar obtained from cereal grains are the common disaccharides. Sucrose consists of two six-carbon sugars, glucose and fructose linked together while in lactose, a molecule each of glucose and galactose are joined together. The two monosaccharide units in maltose are glucose. The structures of these disaccharides are given in Fig.6.5.



(a)



(b)



(c)

Fig. 6.5: Structures of some disaccharides: a) Sucrose, b) Lactose, and c) Maltose

Sucrose is the most widely used natural sweetener. In fact, the sweetness of different natural and synthetic sweeteners is compared with sweeteners sucrose which has been given an index of 100. Fructose, the sweetest natural sweetener has a value of 173.3 while the artificial sweetener, saccharin has a value of greater than ~30000.

Oligosaccharides

The oligosaccharides consist of short chains of monosaccharide units or residues, ranging from 3 to 9, joined by glycosidic bonds. These occur widely in small quantities in plant food products like cereals, such as wheat and rye; vegetables, including onions, garlic, asparagus, and chicory and in bananas and honey. Raffinose is a trisaccharide found in free state in the sugar beet. It consists of a molecule each of galactose, glucose and fructose linked in the same sequence. Stachyose, on the other hand, is a tetra-saccharide found in pea and has four monosaccharides galactose, galactose, glucose and fructose linked in the same sequence. Verbascose is an example of a penta-saccharide. Structures of some of the oligosaccharides are depicted Fig. 6.6.

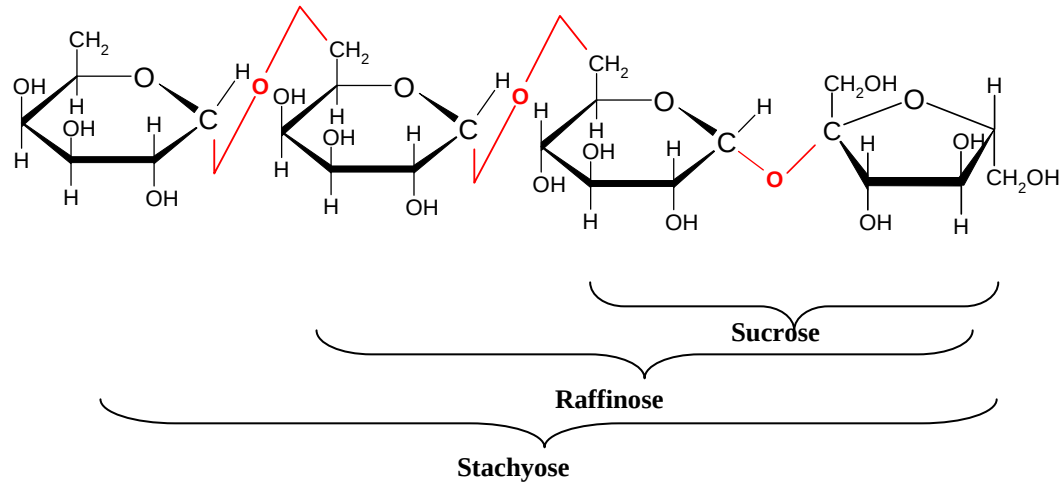


Fig.6.6: Structures of some oligosaccharides

Polysaccharides

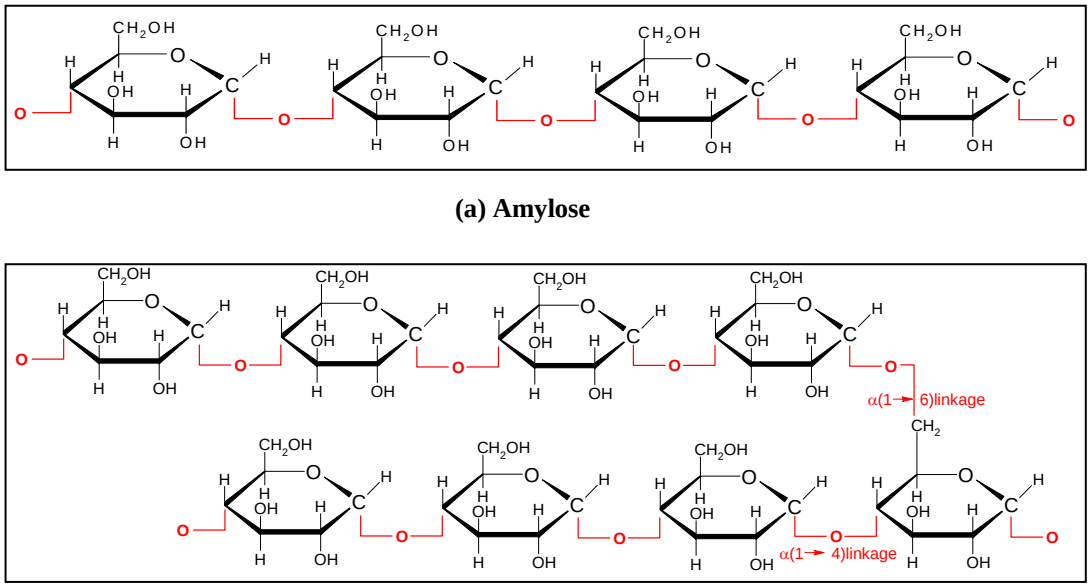
Polysaccharides consist of chains of monosaccharides containing more than 9 units and may extend to hundreds or thousands of units. Some polysaccharide molecules such as cellulose are linear chains, whereas others such as glycogen and starch are mixtures of straight and branched chain molecules.

While sugars form true solutions, polysaccharides due to their polymeric nature form colloidal solutions and are difficult to purify.

Starch is a mixture of two large polymers; amylose, which consists of linear chains of glucose, and amylopectin, which is a highly branched polymer with a higher molecular weight. The structure of starch is shown in Fig. 6.7. Glycogen also has a structure similar to that of starch, the only difference being that the chains are shorter and there are more branches. Polydextrose and

inulin are the polymers of glucose and fructose, respectively. These are used as bulking agents and as sucrose replacements in food products.

In recent past the ß-glucans- the component of the cell wall material in oats and barley have generated interest as "soluble fibre"



(a) Amylose

(b) Amylopectin

Fig. 6.7: Structure of starch: a mixture of amylose and amylopectin

The plant polysaccharides and lignin which are resistant to hydrolysis by the digestive enzyme in human beings are loosely called **dietary fibres**. The main components of dietary or the crude fibre are cellulose, hemicelluloses, hexosans (gallactans and fructosans etc), pectic substances, gums, mucilage and lignin. The dietary fibers are also called the **non-starch polysaccharides (NSP)** discussed as follows.

Non-starch polysaccharides (NSP)

These are composed of a mixture of different polysaccharides containing the pentoses like xylose and arabinose or hexoses like mannose, glucose, and galactose, and uronic acids. In addition to the above plant cell polysaccharides, 'gums' (the substances secreted by plants in response to injury and algal polysaccharides), extracted from algae are also included into NSP or dietary fibres.

Cellulose consists of an unbranched (linear) chain of several thousand glucose units joined by β glycosidic linkages. Since the human digestive enzymes cannot hydrolyze them, these are resistant to digestion.

Hemicelluloses include a range of different polysaccharides with structures comprising linear and branched chains of pentose and hexose units. These have much lower molecular weights than cellulose and may be present in plant foods in water soluble or insoluble forms.

Pectins are water-soluble carbohydrates consisting mainly of chains of galacturonic acids and rhamnose which are branched with chains of pentoses and hexoses. These are present in vegetables and fruits and are prepared mainly from waste citrus peel and apple skin.

Hydrocolloids consist of a wide range of mixed polysaccharides and are derived from seaweed extracts, plant exudates, and seeds. These include gums and mucilage, like guar gum, locust bean gum, agar, and carrageenan. Xanthan gum is a microbial gum consisting of glucose and glucuronic groups.

Having learnt about the structure and classification of carbohydrates, let us now look into some of their important properties, relevant from the quality and food processing point of view.

Check Your Progress Exercise 3

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1) Tick mark (√) in front of correct and mark (X) in front of wrong sentences.
   i) Glucose is the most abundant carbohydrate in nature and is a component of all the carbohydrates.
   ii) A triose is different from a tetrose in having an aldehyde group in place of a carbonyl group.
   iii) Glucose is an aldohexose while fructose is a ketohexose.
   iv) Polysaccharides which can be easily digested by human beings are put into the category of starch polysaccharides where as those which can not be digested are called non-starch polysaccharides.
2) Fill the blanks spaces with appropriate words in the paragraph given below.
   The carbohydrates with a single sugar unit are called……Which along with one more unit forms…….These two types are categorised as…… The carbohydrates which have …….contain more than 9 of such units.
3) Draw the structure of cellulose.

   ……

   ……

   ……

   ……

6.4 PHYSICOCHEMICAL PROPERTIES OF CARBOHYDRATES

You have read that carbohydrates occur in the dissolved state in the living systems. Not all carbohydrates behave in a similar fashion. Though the polysaccharides are composed of monosaccharides only, yet they differ significantly from them in their properties. Some properties in which there are variations between the sugars and the polysaccharides are listed below:

6.4.1 Absorption of Water

All the carbohydrates categorized as simple sugars are good in absorbing moisture and water. Due to this, they are said to be **hygroscopic** in nature. You must have noticed that the sugar crystals get sticky when left in open. However, for some polysaccharides like starch (observed with starch granules and at room temperature), water absorption takes place reversibly.

6.4.2 Solubility

As a matter of common observation, we know that all the sugars dissolve in water easily. The **solubility** of sugars in water affects its use in food preparation and processing. At room temperature the order of solubility is as follows:

fructose > sucrose > glucose > maltose > lactose

The presence of sugar in water increases the boiling point of water. This again is important in food processing. The solubility of polysaccharides like starch is quite different. It is completely insoluble in cold water. However, on heating a solution of starch in water, the granules initially swell up, finally turning into a paste. On cooling most of the starches form a gel, the process is called **gelatinization.**

6.4.3 Mutarotation

Optical activity is the property of some substances to rotate the plane of a plane polarized light to either left or right.

You must have read in your school books about the optical activity of some substances. The optical rotation of the α and β forms of glucose is found to be different. While the α form shows a specific rotation of +112.2°, the value for the β form is +18.7°. Further, when dissolved in water, the specific rotation changes slowly until it reaches equilibrium value of +52.7°. This gradual change in specific rotation from +112.2° or +18.7° to 52.7° is called **mutarotation**. It is a result of the interconversion between the two forms through the open form of glucose to an equilibrium mixture containing 36% α- and 64% β-anomer. The structural changes during mutarotation can be depicted as under.

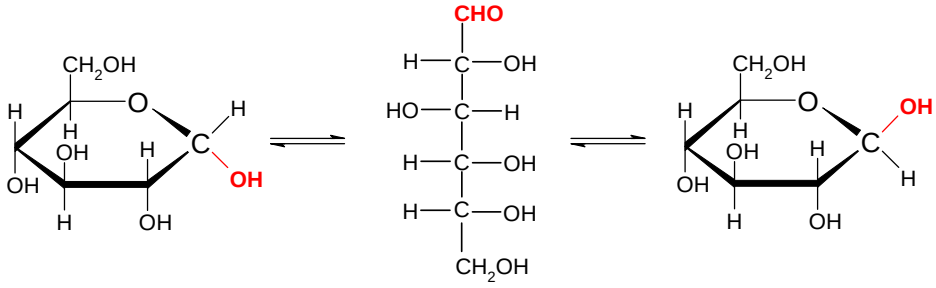


Fig. 6.8: Mutarotation in glucose

6.4.4 Inversion of Sugar

It is an important property of sucrose. Sucrose is dextrorotatory i.e., it rotates the plane of polarized light to right. On hydrolysis with mild acids or an enzyme called ***invertase***, it gives equal amounts of glucose and fructose. Of these two, the glucose is dextrorotatory and fructose is highly laevorotatory (it rotates the plane of polarized light to right). As a result the mixture has a net laevorotation. Since there is an inversion in the direction of rotation, this phenomenon is called inversion of sugar and the sugar is called **invert sugar**. As you know that fructose is sweetest of all sugars, the invert sugar is much sweeter than sucrose and finds extensive applications in confectionary industry.

Food processing operations especially heat processing like; sterilization, cooking and dehydration affect the nature of carbohydrates as you will read in the next section after answering the following exercise.

6.4.5 Taste

All the sugars are **sweet** in taste; their degree of sweetness varies from one another. According to the literature reports the decreasing order of sweetness of these sugars is as follows:

fructose> sucrose > glucose > maltose > lactose

Thus fructose being the sweetest and lactose the least sweet; polysaccharides like starch are tasteless.

6.4.6 Crystallization

Closely related to the property of solubility is crystallization. Crystallization is the process of formation of crystals from the solution of a substance. It has an inverse relationship with the solubility i.e., more soluble the substance, lesser is the tendency to form crystals. Crystallization also depends upon factors like, nature of the solution and addition of some other ingredients in the solution. The property of crystallization finds use in preparation of confectioneries.

In certain food products the crystallization of sugars is undesirable, for example, the crystallization of lactose in sweetened condensed milk or ice creams. This is due to the low solubility of lactose. When milk is condensed to about one third of its volume, the concentration of lactose is large enough to be easily crystallized on cooling. Therefore when the sweetened condensed milk is cooled, the lactose crystallizes out and the crystals may grow to a size that may lead to **grittiness** or **sandiness** in the mouth. This crystallization of lactose may be prevented by a process called seeding, in which finely ground crystals of lactose are mixed with the concentrated product. These micro crystals provide a large number of nuclei for the lactose to crystallize out and as a consequence the size of lactose crystals does not increase much.

6.4.7 Effect of Heat

When sugars are heated, these melt at their melting points. Above the melting points, these dehydrate, decompose and polymerize forming a brown mass called **caramel**. The process of caramel formation is called **caramelization**. Toasting of bread and roasting of rice flakes are some of the examples. Starch also becomes brown on heating and its flavour changes. Besides this, heating changes the solubility of starch. It forms dextrins, becomes more soluble which is desirable in some food preparations.

Different sugars have different caramelization temperatures, for example, galactose, glucose and sucrose caramelize at 160^{o}C, fructose caramelizes at 110^{o}C and maltose caramelizes at 180^{o}C. Caramels produced after heating supers are of deep brown amber colour and with new flavours. We can vary the intensity of colour and flavour by adding acidulates, metal salts etc.

Reducing sugars: Sugars which upon reacting with Benedict's reagent, relives solution containing Cu^{2+} convert it into Cu^{+} ions and yet oxidized.

Maillard reaction: The browning or caramelization of the sugars on heating above their melting points brings about a series of chemical reactions called **Maillard reaction** named after its discoverer Maillard in 1912. Caramelization and Maillard reaction are also referred to as **non-enzymatic browning** reactions.

Maillard reaction is actually the reaction of aldehyde and ketone groups of sugars with amino compounds. The amino groups are usually present in amino

acids, peptides and proteins. The reaction takes place at high temperature. An amino group from a protein combines with an aldehyde or a ketone group of a reducing sugar to produce brown colour and aroma in a variety of foods, including fried foods and baked ones as breads. The reducing sugars are fructose, glucose, maltose, galactose and lactose while sucrose is a non-reducing sugar. The browning in case of baked bread and fried food appears as shown in Fig. 6.9.

Fig. 6.9: Baked and fried foods showing non-enzymatic browning

Check Your Progress Exercise 4

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1) Arrange the following foods in the increasing order of their sweetness and solubility.

Grape juice, wheat grain, milk, cane sugar

……

……

……

6.5 EFFECT OF FOOD PROCESSING ON CARBOHYDRATES

Food processing or cooking can have significant effect on the constituent carbohydrates. During cooking soluble carbohydrates are dissolved e.g. sucrose. Some polysaccharides get hydrolyzed. This may alter the rate and extent of digestion of starch and the properties of dietary fibre. You have read in Section 6.4 about the effect of heat on sugars. Let us understand the effect in case of starch and dietary fibers.

6.5.1 Effect on Starch

Heating the food to cook it and cooling thereafter before consuming have a significant effect on the starchy components of the food. These can be understood in terms of two important phenomenan. These are as follows.

Gelatinization: As mentioned earlier, on heating starch in the presence of water, the crystalline structure of the starch granules is lost irreversibly by a process called **gelatinization**. It is due to absorption of water by starch granules and turning into a jelly like substance. In this process, amylopectin forms the gel and amylase comes into solution. When heating is continued in

excess water, more soluble components of starch come into solution and a paste results. In the food processing, the starch granules are not completely dissolved however, their partial gelatinization is sufficient to allow a good part of the starch to be digested rapidly. In the steaming of food, the process of gelatinization occurs to a small extent whereby a large proportion of slowly digestible starch is preserved.

Retrogradation: The process of re-association of the starch granules on cooling of the gelatinized starch or the starch paste is called **retrogradation**. It depends on the relative proportions of amylose and amylopectin in starch as linear amylose molecules re-associate faster than the highly branched amylopectins. Reheating starchy foods also influences this process. The digestibility of starch in the small intestine is reduced by the degree of processing and retrogradation. The staling of bread is due to retrogradation of starch and the rate of staling is temperature dependent.

6.5.2 Effect on Dietary Fibre

The cereal grains are usually milled to form refined flours which are processed to prepare food products. The milling process removes the fiber-rich outer layers of the grain, and diminishes the total fiber content. The flours of wheat, rye, and maize contain large amounts of cellulose and hemicelluloses. Oat and barley also lose some dietary fiber in the process of milling. Besides the heat treatment can also influence the physical structure and the functional properties of the dietary fiber.

The pectic substances cause thickening of juices, also these are also responsible for mushy nature of vegetables.

Check Your Progress Exercise 5

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1) Choose the correct answer for the following.

The gelatinization of starches

i) is expected to be more if the amylase content is more in the food.

ii) is expected to be more if the amylopectin content is more in the food.

iii) does not depend upon the amylase and amylopectin content of food.

iv) is independent of temperature.

6.6 APPLICATION OF CARBOHYDRATES IN FOODS

Plants use carbohydrates both as a source of energy and as supposing tissue in the same manner that proteins are used by animals

You know that all types of the carbohydrates are widely distributed in nature. Comparatively, large proportions of carbohydrates are found in certain plant tissues. They play a variety of roles as ingredients in various food products. Let us learn about their food applications in detail.

6.6.1 Use of Sugars in Food

The most obvious role of sugar in foods is to impart sweetness. However, these have numerous other functions as well, which make them important ingredients in many foods. Some of these are given below:

Sweetness: 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.

Texture: Sugars make an important contribution to the texture of foods, commonly referred to as 'mouthfeel'. For example, glucose syrups in ice-cream provide it a smooth texture by preventing lactose crystallisation which may give a sandy feeling. In bakery applications, sugars are used to impart flavour, aroma and colour. Further, addition of sugar ensures that the gluten maintains an optimal elasticity, allowing the dough to expand and rise properly. The crisp texture of the bakery products is due to recrystallization of sugar on removal of water during baking. Sugars also acts 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 product and prevent excessive stickiness.

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.

The decomposition of sugar during fermentation is identical with the reactions by which sugar begins to burn during respiration.

Fermentation: The production of chemicals by fermenting various sugars has been in practice since long. 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. *Zymase*, an enzyme from yeast, changes the simple sugars into ethanol and carbon dioxide. The fermentation reaction can be represented by the following simple equation.

$$C_6H_{12}O_{16} \longrightarrow 2CH_3CH_2OH + 2CO_2$$

Sugars, which are used to activate yeast for fermentation, are important in the brewing and baking industries.

Appearance*:* You have read in Sec 6.4 that two major types of non-enzymatic browning reactions i.e. Caramelization and Maillard reaction have been recognised to occur in foods during processing. The colour of bread crust is a result of Maillard reaction. The golden brown crisp surface formed as a result of caramelization enhances flavour and taste and also helps in retaining the moisture.

Freezing Point*:* Sugars are effective in lowering the freezing point of a solution. Monosaccharides and corn syrups, containing a high proportion of low molecular weight sugars are most effective at lowering the freezing point. Reducing sugars such as glucose, fructose maltose and lactose are recommended for icecream. In frozen desserts, sugars give flavour and mouthfeel.

Antioxidants*:* Many carbohydrates are excellent scavengers of 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 product have been employed in the food industry as food additives for biscuits, cookies and sausages.

Check Your Progress Exercise 6

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1) Match the statement given in column A with the term given column B correctly

Column A		Column B	
a)	Fermentation of sugars	i)	Antioxidant
b)	Food presentation by retarding catalytic oxidation	ii)	Caramelization
c)	Formation of crust in bread	iii)	Zymase enzymes

6.6.2 Food Applications of Starch Polysaccharides

Starches find numerous applications in food because of easy availability and low cost. These include the following.

Thickener: You know that starch absorbs water and swells up. If the amylose content of the starch is more, its long water soluble chains increase the viscosity and thickens gravies, sauces and pudding.

Fat replacer: The water absorbing property of starches is also responsible for the mouthfeel of many food products containing them and may be used as fat substitutes e.g. in salad dressings and dairy products.

Humans utilise carbohydrate not only for heir food, but also for their clothing (cotton, linen, rayon), Sheller (wood), fuel, and paper wood.

Water binder: As starch readily absorbs moisture, it checks its escape from the food product and in some dishes like cakes, it retains the moisture and yet does not allow it to be wet. The high water binding ability of starches leading to their swelling up can provide body and texture to the food stuff.

The partial hydrolysis of starch yields dextrins (glucose polysaccharides of intermediate size). These are more easily digested than starch and therefore are extensively used in the preparation of infant foods.

Besides these, starches find applications as **adhesives** (in stamps), **binder** (in formed meats and breaded items); and as **bulking agent** (in baking powder, fat).

Modified starch*:* The starches in their native form or as they are available in nature do not fulfill all the desirable requirements. In order to have better usefulness, starches are treated to alter one or more original characteristic. These are called modified starches and are with improved characteristics. Modified starches find applications in instant desserts, jellies, salad dressings, canned soups and many more.

6.6.3 Food Applications of Non-starch Polysaccharides

You have learnt before that the non-starch polysaccharides are a mixture of substances found in the cell wall of plants, giving them form and structure. Some of their important food applications are:

Cellulose: The most important application of cellulose is in 'water retention'. The dry amorphous cellulose becomes soft and flexible on absorbing water. Besides this, the cellulose finds applications as emulsifier, anticaking agents, dispersing agent, thickener and gelling agent. Cellulose also is used to improve the volume and texture of food. In addition, an important derivative of cellulose i.e., carboxymethyl cellulose (CMC) also finds many applications as a stabilizer due to its being soluble in cold water.

Hemicelluloses: It finds applications as emulsifier, stabilizer and binder in flavour bases, dressings and pudding mixtures. These are also used as bulking agents and as fat replacer.

Pectins: These find extensive applications as gelling agents in jams and jellies besides being water binders, thickeners and stabilizers.

Hydrocolloids: Find applications as thickening, gelling, stabilizing, or emulsifying agents in some food products. The microbial gums are finding wide food applications today, for example dextran gums are readily soluble in water.

Fig. 6.10: Carbohydrates find various food applications

Check Your Progress Exercise 7

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1) From the list give below, pick up the applications of the starch related to its water binding capacity.

   i) Preparation of infant foods

   ……

   ……

   ……

   ii) Salad dressings

   ……

   ……

   ……

iii) Adhesives

……

……

……

iv) Binder

……

……

……

6.7 NUTRITIONAL AND CLINICAL IMPORTANCE

According to American Association of Cereal Chemists, dietary fibre may be defined as "the edible parts of plants or analogues of carbohydrates that are resistant to digestion and absorption in the small intestine, with complete or partial fermentation in the large intestine."

You are aware that simple as well as complex carbohydrates are one of the most significant nutrients as these meet most of the energy requirements. However, all the carbohydrate constituents in the food do not participate in the energy generation and have many other nutritional roles.

A significant component of starches in the diet does not get degraded in the stomach and is called resistant starch. These are also grouped into dietary fibres and serve as substrate for the intestinal microflora which synthesise important vitamins.

Hemicelluloses are good sources of dietary fibre and stimulate the immune system. These are also good for promoting weight loss, relieving constipation and controlling carcinogens in the intestinal tract. These are also helpful in reducing postprandial serum glucose level; reduce insulin response and serum cholesterol level.

Certain hydrocolloids also have positive health effects. These are good laxatives. Dietary intake of hydrocolloids are associated with the reduction of blood glucose level, insulin response and cholesterol lowering effect.

Some people are unable to digest lactose due to deficiency of enzyme lactase, these people are **lactose intolerant**. In such cases, some of the unhydrolyzed lactose passes into the intestine and its presence tends to draw fluid into interstitial rumen by osmosis. Intake of milk by them leads to abdominal distention, cramps and diarrhoea.

From a nutritional standpoint, sugars should be consumed in relatively small quantities as they provide no other nutrients than carbohydrates. This recommendation is made so that individuals will avoid consuming a disproportionate number of calories without a corresponding proportion of vitamins, minerals and proteins. Further, excessive consumption of large amounts of carbohydrates, particularly fructose and sucrose, over a long term are found to cause an elevation in triglyceride concentration, and LDL, production of low density lipoproteins (LDL and very low DL) which may lead to heart stroke.

6.8 LET US SUM UP

Carbohydrates are very important biomolecules occurring in nature as part of plant and animal tissues and also produced by microbes. The carbohydrates were earlier named on the basis of their sources e.g. sucrose from cane sugar, fructose from fruits, maltose from malt etc. Carbohydrates were initially thought to be hydrates of carbon. However, their structure reveals that these are polyhydroxy compounds with an aldehyde or a ketonic group in the chain. The chain may contain three monosaccharide units to hundreds of them.

Food scientists classify carbohydrates into three main categories depending upon the complexity of structure. These categories are simple sugars comprising of mono and disaccharides, oligosaccharides with 3 to 9 monosaccharide units in them and polysaccharides having more than 9 such units. The polysaccharides are further divided into two types; starch and non-starch polysaccharides. The latter also called dietary fibre include cellulose and hemicelluloses, pectin and hydrocolloids.

All the carbohydrates depict properties which yield them great utility. They provide sweetness to foods and have good water absorbing ability. They lower the freezing point, increase boiling point and change colour and flavour on heating. The last property is known by the terms caramelization and Maillard reaction. These are known as non-enzymatic browning reactions. The sugars on cooking or heating show non-enzymatic browning while the starches undergo gelatinization and retrogradation. Another characteristic property of carbohydrates is their existence in two forms called α and β forms. It is referred to as mutarotation and depicts a change in optical activity. All types of carbohydrates find applications in food industry. They are used as thickeners, sweeteners, binders, gelatinizers, fat replacers and find use in frozen deserts and ice creams because of their ability to lower the freezing point etc. Besides their application in food preparation and processes, carbohydrates have a lot of nutritional and clinical importance. The simple sugars are good energy sources while the complex ones, especially the non-starch polysaccharides are good sources of dietary fibers.

6.9 KEY WORDS

Anti-oxidants : Substance that reduces oxidative damage by scavenging free electrons.

Caramelization : Caramelization is the process of removal of water from a sugar (such as sucrose or glucose) followed by isomerization and polymerization steps.

Crystallization : Crystallization refers to the formation of solid crystals from a homogeneous solution. It is essentially a solid-liquid separation technique and a very important one at that.

Dietary Fibre : Dietary fibers are the indigestible portion of plant foods that move food through the digestive system and absorb water. Dietary fiber consists of non-starch polysaccharides such as cellulose and many other plant components such as dextrins, inulin, lignin, waxes, chitins, pectins, beta-glucans and oligosaccharides.

Gelatinization : Formation of a water-retentive gel by expansion of starch granules when heated in moist conditions. Starch swells up by heating and continues to absorb water and showing more viscosity and clarity along with increase of temperature and then will reach to maximum viscosity.

Hydrocolloids : A hydrocolloid is defined as a colloid system wherein the colloid particles are dispersed in water. A hydrocolloid has colloid particles spread throughout water and depending on the quantity of water available can take on different states, e.g., gel or sol (liquid). Hydrocolloids are thickening, gelling and stabilizing agents, which play a major role in numerous food and beverage products.

Inversion : A mixture of equal parts of glucose and fructose resulting from the hydrolysis of sucrose. It is found naturally in fruits and honey and produced artificially for use in the food industry. is important in the manufacture of sugar confectionery, and especially boiled sweets, since the presence of 10-15% invert sugar prevents the crystallization of sucrose.

Lactose Intolerance : Lactose intolerance is an inability to digest and absorb lactose (the sugar in milk) that results in gastrointestinal symptoms when milk or products containing milk are drunk or eaten.

Inversion : A mixture of equal parts of glucose and fructose resulting from the hydrolysis of sucrose. It is found naturally in fruits and honey and produced artificially for use in the food industry. is important in the manufacture of sugar confectionery, and especially boiled sweets, since the presence of 10-15% invert sugar prevents the crystallization of sucrose.

Maillard Browning : The Maillard reaction is a chemical reaction between an amino acid and a reducing sugar, usually requiring heat. Like caramelization, it is a form of non-enzymatic browning. The reactive carbonyl group of the sugar reacts with the nucleophilic amino group of the amino acid, and forms a variety of interesting but poorly characterized molecules responsible for a range of odors and flavors.

Modified Starch : Modified starch are normal natural starches that have been altered chemically or physically to assist in the food processing industry. They can be cross-bonded, esterified or converted by acids or enzymes to have greater viscosity, clarity etc. They have used in canning, instant puddings, frozen foods etc.

Mutarotation : Mutatrotation is the term given to the change in the specific rotation of a cyclic monosaccharide as it reaches an equilibrium between its α and β anomeric forms. Though the cyclic forms are usually heavily favoured, liquid monosaccharides (or monosaccharaides in aqueous solution) are always in equilibrium with their straight-chain forms. This equilibrium is established as the hemiacetal bond between C1 (the only carbon bound to two oxygens) and C5 is cleaved (forming the straight-chain compound) and reformed (forming the cyclic compound). When the hemiacetal bond is reformed, the OH group on C5 may attack either of the two stereochemically distinct sides of the aldehyde group that contains C1. Which side it actually does attack on decides whether the α or β anomer is formed.

Retrogradation : Some starch gels may lack stability and slowly exude water through the gel surface. Although amylose is soluble in the hot gelatinized starch mixture, it tends to become insoluble in the cooled mixture. This phenomenon is called retrogradation and it occurs when the amylose chains bind together in helical and double helical coils. Retrogradation affects the texture of the food product and it also lowers the digestibility of the product.

Syneresis : The separation of liquid from a gel caused by contraction of gelling agents.

6.10 TERMINAL QUESTIONS

1) What are the main sources of carbohydrates in nature? Give two examples of carbohydrates for each source?

2) How is the existence of α and β forms of glucose explained?

3) How are the carbohydrates generally classified? Write the types and explain in brief.

4) Explain and differentiate caramelization and Maillard reaction?

5) How do sugars help in extending the shelf-life of baked products?

6) What are dietary fibre structurally? How are these nutritionally important?

6.10 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1) (iv)

Check Your Progress Exercise 2

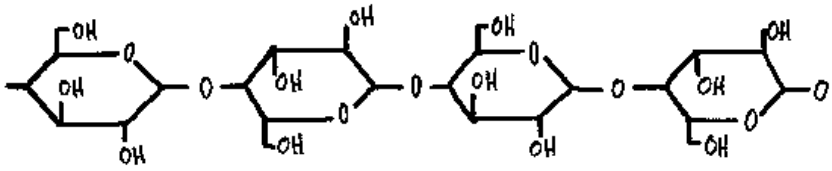
1) Five membered rings (called furanose)

Check Your Progress Exercise 3

1) (i) x (ii) x (iii) √ (iv) √

2) monosaccharides, disaccharides, simple sugars, polysaccharides

3)



Check Your Progress Exercise 4

1) grape juice > cane sugar > wheat grain > milk

Check Your Progress Exercise 5

1) (ii)

Check Your Progress Exercise 6

1) a. (iii)
   b (i)
   c (ii)

Check Your Progress Exercise 7

1) (ii)

6.11 ANSWERS TO TERMINAL QUESTIONS

1) Plants, animals and microbes (xanthan and gellan gums). The existence of these forms can be explained on the basis of mutarotation.

2) The phenomenon of mutarotation is observed when the solution of glucose shows a change in specific rotation from 112.2^{o} to 52.7^{o} and then to 1.

3) Carbohydrates are generally classified on the basis of the complexity of their structure. They are classified into simple and complex types. The simple carbohydrates include mono-, di- and oligosaccharides while the complex ones have polysaccharide. The polysaccharides are further divided into starch and non-starch polysaccharides.

4) Both the phenomena are a result of heating the carbohydrates at high temperature in presence of moisture the non-enzymatic browning in case of caramelization gives rise to brown colour and flavour to the food. In maillard reaction, the carbonyl group of the carbohydrates (especially the reducing sugars) in foods reacts with amino group of proteins and gives brown colour and flavour to the baked products.

5) Sugars are good in absorbing moisture. When put into the foods to be baked these absorb the moisture and do not allow microbes to grow. This increase the shelf life of that food.

6) The non-starch polysaccharides that are not digestible are also called dietary fibers. These include cellulose, hemicelluloses etc. the dietary fibers act as substrates for intestinal microflora which synthesise important vitamins. Also they function to stimulate the immune system.

6.12 SOME USEFUL BOOKS

Lee A. Frank (1983). *Basic Food Chemistry*, The AVI Publishing Company Inc.

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