
UNIT 6 CARBOHYDRATES

Structure

- 6.0 Objectives
- 6.1 Introduction
- 6.2 Occurrence
- 6.3 Structure and Classification
 - 6.3.1 Structure of Carbohydrates
 - 6.3.2 Classification of Carbohydrates
- 6.4 Physicochemical Properties of Carbohydrates
 - 6.4.1 Absorption of Water
 - 6.4.2 Solubility
 - 6.4.3 Mutarotation
 - 6.4.4 Inversion of Sugar
 - 6.4.5 Taste
 - 6.4.6 Crystallization
 - 6.4.7 Effect of Heat
- 6.5 Effect of Food Processing on Carbohydrates
 - 6.5.1 Effect on Starch
 - 6.5.2 Effect on Dietary Fibre
- 6.6 Application of Carbohydrates in Foods
 - 6.6.1 Use of Sugars in Food
 - 6.6.2 Food Applications of Starch Polysaccharides
 - 6.6.3 Food Applications of Non-starch Polysaccharides
- 6.7 Nutritional and Clinical Importance of Carbohydrates
- 6.8 Let Us Sum Up
- 6.9 Key Words
- 6.10 Terminal Questions
- 6.11 Answers to Check Your Progress Exercises
- 6.12 Answers to Terminal Questions
- 6.13 Some Useful Books

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 (\checkmark) 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

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.

Aldehyde: $RCHO$
Ketone: R_1R_2CO

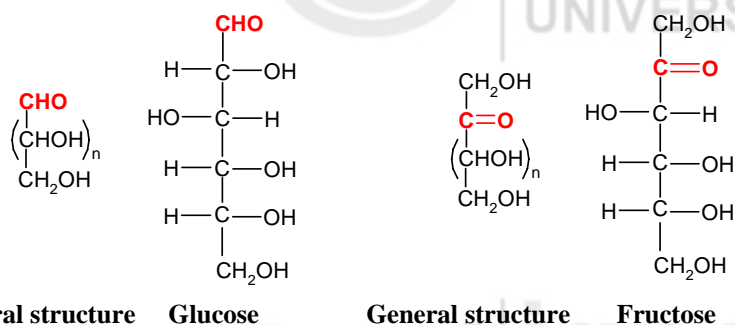


Fig. 6.1: Structures of (a) polyhydroxyaldehydes, and (b) polyhydroxyketones

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.

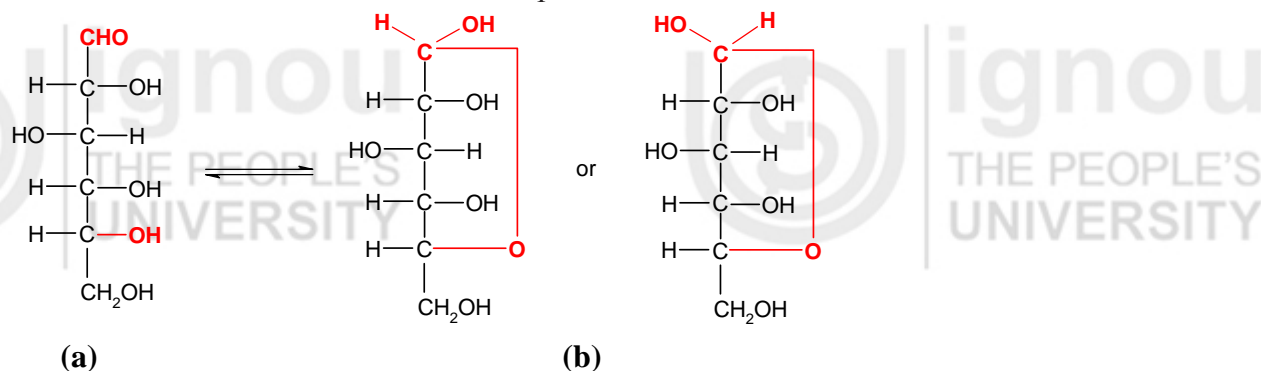


Fig. 6.2: (a) Open chain, and (b) Cyclic hemiacetal structures of glucose

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.

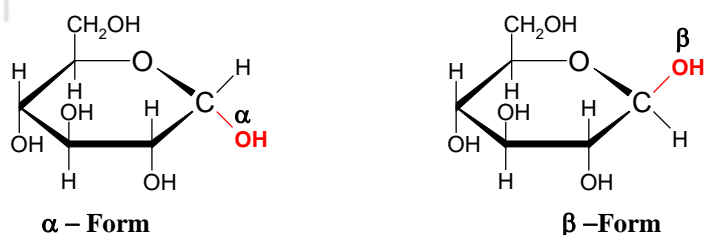


Fig. 6.3: Pyranose structures of glucose

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.

- 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.

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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 polyhydroxyaldehyde 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.

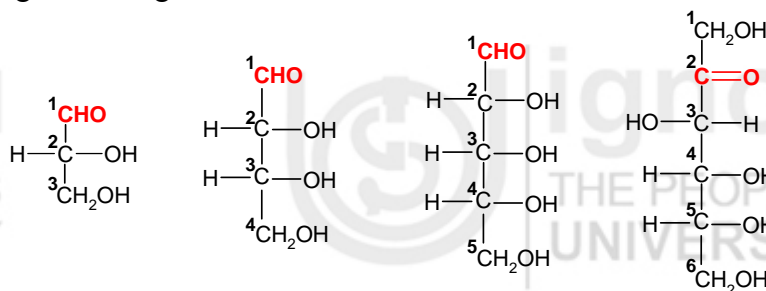
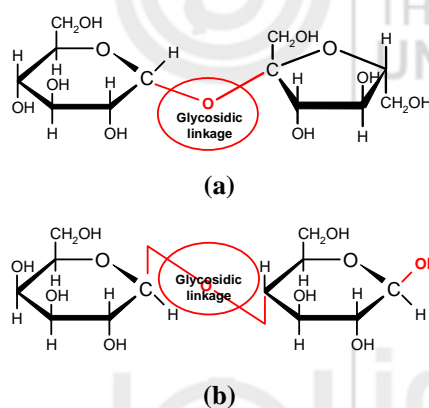


Fig. 6.4: Structures of some monosaccharides with different number of carbon atoms

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.



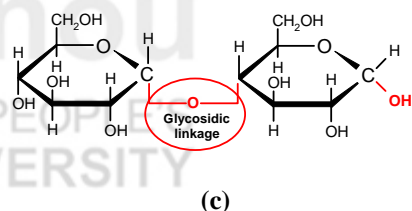


Fig. 6.5: Structures of some disaccharides: a) Sucrose, b) Lactose, and c) Maltose

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.

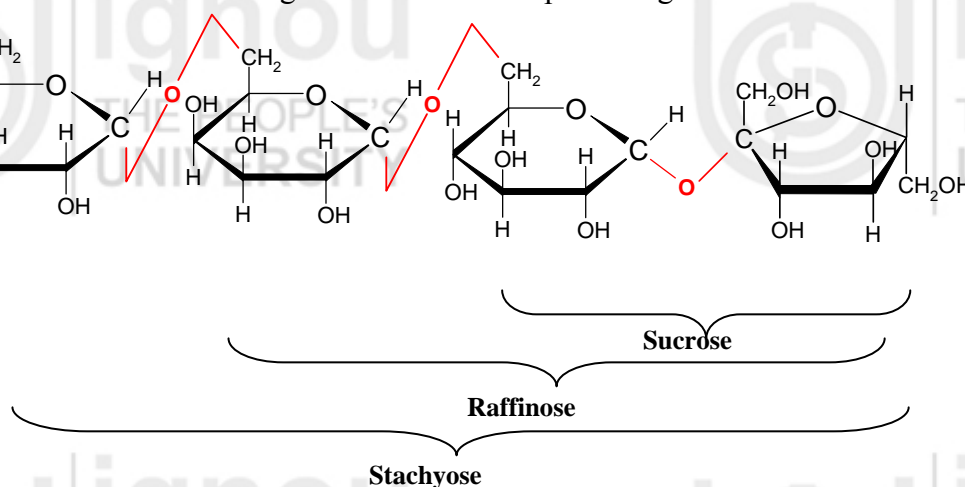


Fig.6.6: Structures of some oligosaccharides

Polysaccharides

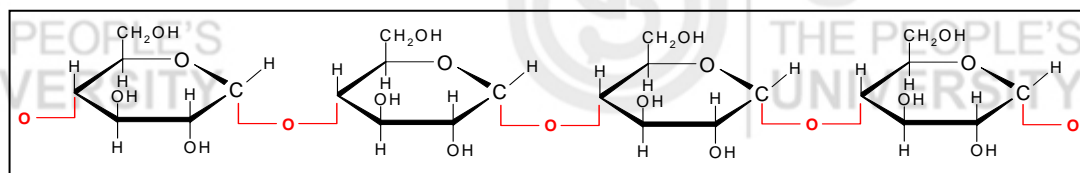
Polysaccharides consist of chains of monosaccharides containing more than 9 units and may extend to hundreds or thousands of units. Some polysaccharide molecules such as cellulose are linear chains, whereas others such as glycogen and starch are mixtures of straight and branched chain molecules.

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

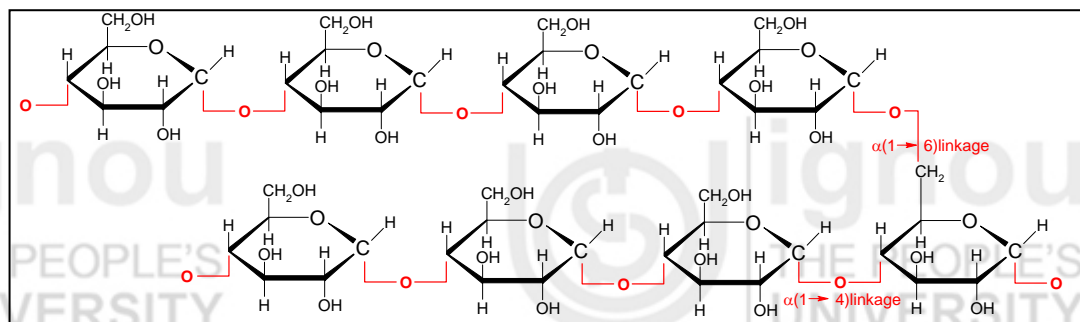
While sugars form true solutions, polysaccharides due to their polymeric nature form colloidal solutions and are difficult to purify.

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 β -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 whereas those which cannot be digested are called non-starch polysaccharides.

2) Fill the blank 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 havecontain more than 9 of such units.

3) Draw the structure of cellulose.

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6.4 PHYSICO-CHEMICAL PROPERTIES OF CARBOHYDRATES

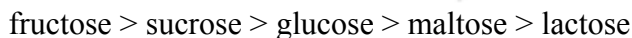
You have read that carbohydrates occur in the dissolved state in the living systems. Not all carbohydrates behave in a similar fashion. Though the polysaccharides are composed of monosaccharides only, yet they differ significantly from them in their properties. Some properties in which there are variations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



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 $+112.2^\circ$, the value for the β form is $+18.7^\circ$. Further, when dissolved in water, the specific rotation changes slowly until it reaches equilibrium value of $+52.7^\circ$. This gradual change in specific rotation from $+112.2^\circ$ or $+18.7^\circ$ 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.

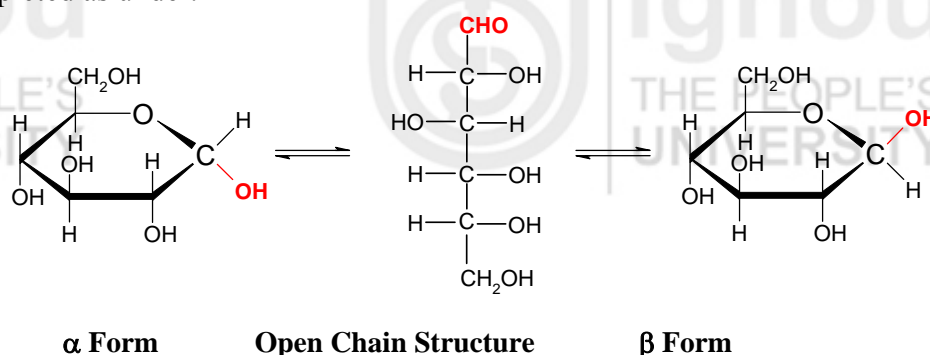


Fig. 6.8: Mutarotation in glucose

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 left). 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 dextrans, 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°C, fructose caramelizes at 110°C and maltose caramelizes at 180°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.

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

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

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

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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 phenomenon. 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

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:

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

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.

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.



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

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

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.

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 dextrans (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.

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

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

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.....

iv) Binder

.....

.....

.....

6.7 NUTRITIONAL AND CLINICAL IMPORTANCE

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.

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.”



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 dextrans, 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 : Mutarotation 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 monosaccharides 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

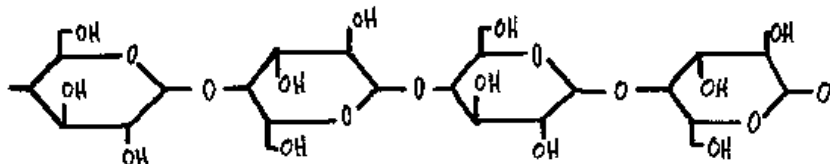
- 1) (iv)

Check Your Progress Exercise 2

- Five membered rings (called furanose)

Check Your Progress Exercise 3

- (i) x (ii) x (iii) \checkmark (iv) \checkmark
- monosaccharides, disaccharides, simple sugars, polysaccharides
-

**Check Your Progress Exercise 4**

- grape juice > cane sugar > wheat grain > milk

Check Your Progress Exercise 5

- (ii)

Check Your Progress Exercise 6

- (iii)
 - (i)
 - (ii)

Check Your Progress Exercise 7

- (ii)

6.11 ANSWERS TO TERMINAL QUESTIONS

- Plants, animals and microbes (xanthan and gellan gums). The existence of these forms can be explained on the basis of mutarotation.
- The phenomenon of mutarotation is observed when the solution of glucose shows a change in specific rotation from 112.2° to 52.7° and then to 1.
- 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.
- 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.

deMan (1980). *Principles of Food Chemistry*, The AVI Publishing Company Inc.

Swaminathan M. (1999). *Essentials of Food and Nutrition, Vol. I*. The Bangalore Printing and Publishing Co. Ltd., Bangalore

Bennion Marion (1980). *The Science of Food*, Wiley John and sons

Manay N. Shakuntala, and M. Shadaksharaswamy (1987). *Foods: Facts and Principles*, Wiley eastern Ltd.

Mudambi R. Sumati and Rao Shalini (1985). *Food Science*, Wiley Eastern Ltd.

UNIT 2 CARBOHYDRATES

Structure

- 2.0 Objectives
- 2.1 Introduction
- 2.2 Importance and Functions of Carbohydrates
 - 2.2.1 Carbohydrates as a Basic Fuel for Energy to Body
 - 2.2.2 Carbohydrates as Chief Dietary Constituents
 - 2.2.3 Carbohydrates in Different Role in Biological Systems
- 2.3 Classification
 - 2.3.1 Monosaccharides
 - 2.3.2 Oligosaccharides
 - 2.3.3 Polysaccharides
- 2.4 Sources of Carbohydrates
- 2.5 Clinical Applications of Carbohydrates
 - 2.5.1 Hypoglycemia
 - 2.5.2 Lactose Intolerance
 - 2.5.3 Diabetes Mellitus
 - 2.5.4 Other Conditions
- 2.6 Dietary Fibers and its Importance
 - 2.6.1 Carbohydrate Content of Meat
 - 2.6.2 Physiological Properties of Fibers
 - 2.6.3 Clinical association Between Dietary Fiber and Various Diseases
- 2.7 Let Us Sum Up
- 2.8 Key Words
- 2.9 Some Useful Books
- 2.10 Answers to Check Your Progress

2.0 OBJECTIVES

After reading this unit, you will be able to:

- narrate the importance of carbohydrates in diet;
- explain chemical nature, sources and functions of carbohydrates in diet; and
- explain the importance of carbohydrates in treatment/prevention of many diseases.

2.1 INTRODUCTION

Whatsoever organic material present in a living system are mainly classified under carbohydrates, proteins and lipids. All these three play a vital role not only in the structure but also in the functionality of body. The literal meaning of carbohydrate is hydrate of carbons. Carbohydrates are compounds of carbon, hydrogen and oxygen represented by empirical formula $C_n(H_2O)_n$. As per the definition, carbohydrates are "polyhydroxy (more than one OH group) aldehyde or polyhydroxy ketone". Our body has been designed and developed to solve the basic survival problems such as energy to do its work, materials to build and maintain its form and agents to control these processes efficiently. Key nutrients

of the food we eat provide solution to these life-sustaining problems. Our body's primary fuel is carbohydrate, which provides energy. Energy is a primary necessity of life. (Energy is the capacity of an organism by which he can do work.)

2.2 IMPORTANCE AND FUNCTIONS OF CARBOHYDRATES

You have already studied that carbohydrates are primary fuel of the body i.e., the source of energy. Beside this, they also play various important roles in the body. Importance of carbohydrates in the body can be explained in the following way:

2.2.1 Carbohydrates as a Basic Fuel for Energy to Body

Starches and sugars are the basic fuel forms of carbohydrates that occur in our food.

Plants by the process of photosynthesis transform sun energy into a typical form of carbohydrate specially found in plant known as starch. In this process, carbon dioxide from the air and water from the soil are converted into starch and sugar by chlorophyll, the green pigment present in leaves.

Carbohydrates are called "quick energy" foods. This is because they are rapidly broken down in the body to provide energy. About 50 to 60 per cent of total kilocalorie requirement of a person comes from dietary carbohydrates. The amount of carbohydrates stored in the body is relatively small. Stored glycogen and glucose can provide energy sufficient for about half a day at moderate activity. Thus regular intake of carbohydrates containing food at moderately frequent intervals is essential to meet the constant energy demands of the body.

2.2.2 Carbohydrates as Chief Dietary Constituents

Carbohydrates are one of the major components of the diets all over the world. The reason behind this is their wide availability and lower cost. They may be grown and stored easily. Carbohydrates rich foods can be kept in dry storage for relatively longer period without spoilage. In some countries, carbohydrates constitute almost entire diet of the people.

2.2.3 Carbohydrates in Different Role in Biological Systems

Glucose: This is the most important carbohydrate. It is absorbed into the blood stream after the digestion of food. It can be converted into other forms of carbohydrates in the body. Glucose can also be obtained from complex carbohydrates by degradation in the liver. It is from glucose that all other carbohydrates in the body are formed. Glucose is a major fuel of the tissues of mammals (except ruminants) and a universal fuel of the fetus. It is converted to other forms of carbohydrates having highly specific functions. Some of the special functions of carbohydrates in body tissues are as follows:

- i) **Stored form of energy:** In living system glycogen and starch are stored form of energy. Glycogen is found in animals whereas starch in plants. Glycogen reserved in liver and muscle of animal provide a constant supply of glucose to fulfil energy needs of the body. Thus, this reserve protects cells from depressed metabolic functions and injury.

- ii) **Protein sparing function:** Carbohydrates regulate protein metabolism. Presence of sufficient carbohydrates prevents the breakdown of protein for energy requirement so that the proteins are used in the body for its basic structural purpose of tissue building. Excess of carbohydrates in body is utilized for the carbon skeleton of protein.
- iii) **Antiketogenic effect:** Carbohydrates also regulate the fat metabolism. The amount of carbohydrates in the diet decides the formation and disposal rate of ketones from lipids. If a carbohydrate is inadequate or unavailable for energy needs, excess fat is oxidized leading to accumulation of ketones and results in ketoacidosis. Excess of carbohydrate is transformed into fats. It should be noted that fat and protein always burn in flame of carbohydrate i.e., even for oxidation of fat or protein as energy source, some carbohydrate or its metabolite is required.
- iv) **Heart action:** Heart action is a life sustaining muscular exercise. Glycogen reserve in cardiac muscle is an important emergency source of contractile energy. Low carbohydrate intake or poor glycogen stores may cause cardiac symptoms and angina.
- v) **Central nervous system function:** The brain, central nervous system regulatory centre do not contain stored glucose and are dependent on glucose supply from the blood. Hypoglycemia, (decrease in blood glucose level), may cause irreversible brain damage. So, carbohydrates are necessary for functional integrity of nerve tissue.

Check Your Progress 1

- 1) Why carbohydrates are known as quick energy foods?

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- 2) What is the percentage of energy provided by carbohydrates for normal functioning of the body?

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- 3) Name any two stored form of carbohydrates.

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4) Why carbohydrates are the major component of our diet?

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5) What are the functions of carbohydrates in our body?

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6) Discuss (a) Antiketogenic effect (b) Protein sparing function of carbohydrates?

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7) Name the emergency source of contractile energy of cardiac muscle.

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8) Write the role of glucose in central nervous system.

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2.3 CLASSIFICATION

Carbohydrates or saccharine (Greek: Sacharon, sugar) means "carbon hydrate" which is $(CH_2O)_n$ wherein $n > 3$. Carbohydrates are classified according to the number of basic sugar or saccharide unit.

2.3.1 Monosaccharides

Monosaccharides are the simplest form of carbohydrate known as simple sugar. Monosaccharides are classified according to their functional group and number of carbon atoms.

Aldoses: If the functional group is aldehyde, as in glucose, it is referred as aldose.

Ketoses: If the functional group is ketose, as in fructose, it is referred as ketoses. Trioses are the smallest monosaccharides of three carbon atoms. Those with four, five, six, seven carbon atoms are tetroses, pentoses, hexoses, and heptoses respectively. Six-carbon aldose is an aldohexose and of ketose is ketohexose.

The three main monosaccharides important in human nutrition are glucose, fructose and galactose.

Glucose: Naturally preformed sweet sugar, glucose is found only in few foods such as corn syrup. Digestion of starch produces glucose. In body, all other types of sugars are converted to glucose. It is also known as "dextrose". (Normal blood sugar level is about 70 -110 mg /100 ml.) Glucose is the ultimate energy fuel, which is oxidized in cell to give energy.

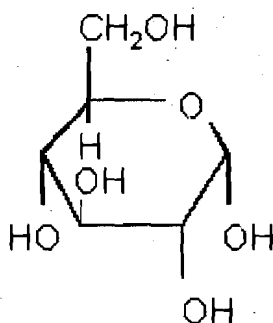


Fig. 2.2: Structure of Glucose

Fructose: It is the sweetest simple sugar. Fructose is found in fruits as honey. Fructose is converted into glucose in our body to provide energy.

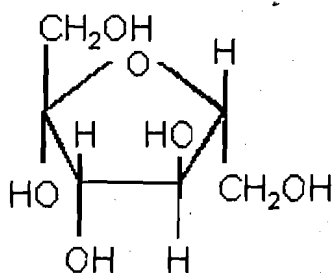


Fig. 2.3 Structure of Fructose

Galactose: It is not found in free-form in food, but is produced from lactose (milk sugar). Galactose is also changed to glucose for energy, which is a reversible reaction. During milk production, glucose is converted to galactose. Galactosemia, a genetic disorder, is due to the absence/ deficiency of the enzyme required for the conversion of galactose to glucose and thus galactose accumulates.

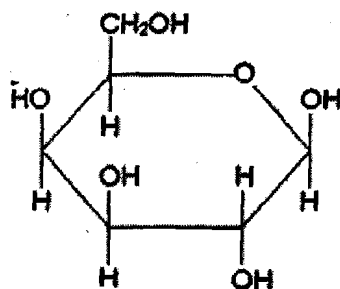


Fig. 2.4: Structure of Galactose

2.3.2 Oligosaccharides

Oligosaccharides are composed of 2 -10 monosaccharides linked together. Those with two monosaccharides unit are called disaccharides. The three main disaccharides of physiological importance are sucrose, lactose and maltose.

Sucrose: Sugarcane beet is a rich source of sucrose. It is a common disaccharide. Sucrose can be found in all molasses, some fruits and vegetables such as pineapple, carrot etc.

Lactose: Lactose is also known as milk sugar. During lactation, it is formed in the body from glucose. It is 1/6th as sweet as sucrose. Cheese, a milk product, has very little or no lactose.

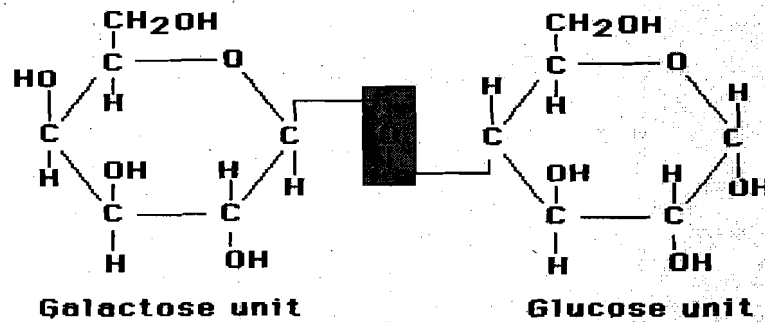


Fig. 2.5: Structure of Lactose

Maltose: Commercial malt products of starch breakdown and germinating cereal grains are the rich source of maltose. It is an important metabolic carbohydrate and an intermediate product of starch digestion.

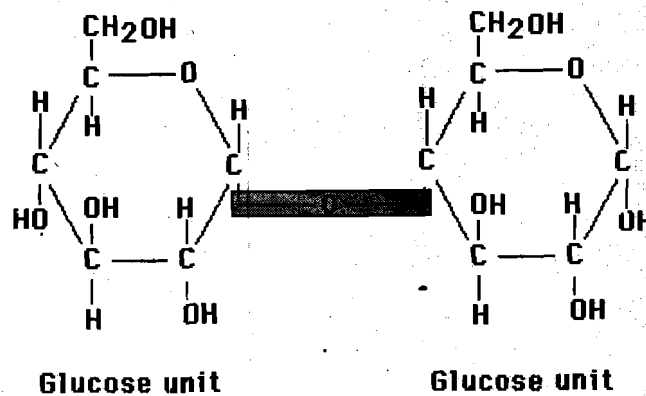


Fig. 2.6: Structure of Maltose

2.3.3 Polysaccharides

Polysaccharides are made up of many saccharides (simple sugar) units. The most important polysaccharide in human nutrition is starch. Other polysaccharides are glycogen and dextrin. The bulk of animal diet is composed of non-digestible forms of dietary fiber e.g., cellulose. Polysaccharides are of two types: Homopolysaccharides and Heteropolysaccharides.

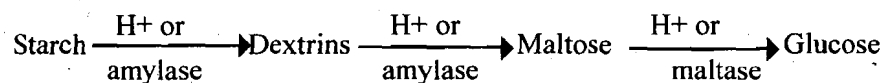
i) Homopolysaccharides

They yield only one type of monosaccharide (glucose) upon complete hydrolysis. Some important homopolysaccharides are as follows:

Starch: It is made up of many glucose units attached in a branch chain manner. Actually, it is a mixture of two polymers, amylose (10-20 per cent) and

amylopectin (80-90 per cent). It yields only glucose on digestion. Starch is the most important source of dietary carbohydrate in the world. It is an important part/component of human nutrition and health. In many countries, starch is the staple food material forming the bulk of the diet. Cereal grains, legumes, potatoes and many vegetables are rich in starch.

Dextrin: Dextrin is formed as an intermediate product in the break down of starch.



Glycogen: The storage carbohydrate in animals is glycogen, also known as animal starch. In fact, it is a polymer of glucose similar to amylopectin but with high branching and its branches are smaller. It is formed during cell metabolism and stored in small amounts in liver and muscle tissues. During fasting period such as sleep hours, glycogen provides immediate energy fuel or glucose for muscle action. Dietary carbohydrates are needed to maintain glycogen stores. Low dietary carbohydrate intake causes symptoms like fatigue, dehydration and excessive protein breakdown.

Cellulose: Cellulose is the main component of the framework of plant cell wall. The repeating unit is a disaccharide cellobiose which is made up of two units of D glucose joined by β -1, 4 glucosidic linkage. It provides most of the substances labeled "crude fiber". The main food sources are stem and leaves of vegetables, seed and grain coverings, skin and hulls. Humans cannot digest cellulose. Humans lack the necessary digestive enzymes which can break β -1, 4 glucosidic linkage. Therefore, cellulose remains undigested. Non-cellulose fibers absorb water and have slow gastric emptying time. They are gum like water-soluble substances that aid in binding cholesterol and controlling its absorption. They provide bulk for normal intestinal muscle action to prevent colon pressure.

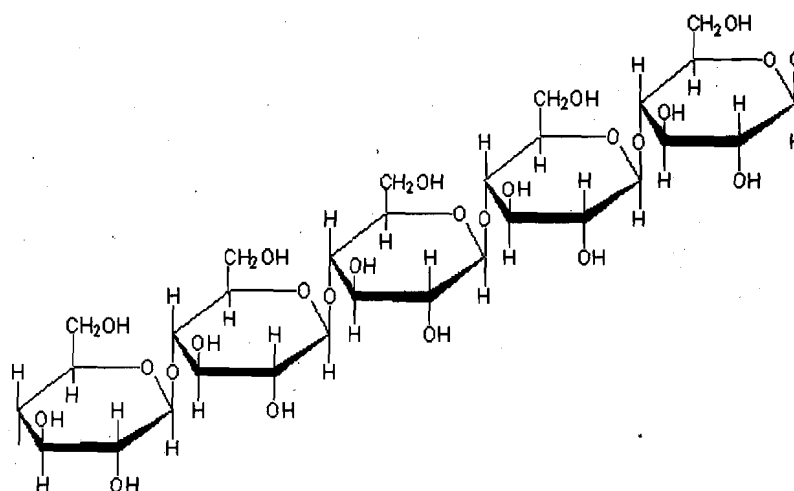


Fig. 2.7: Structure of Cellulose

ii) Heteropolysaccharides

These are the polysaccharides, which on complete hydrolysis yield more than one particular type of components (sugar acids, amino sugars as non-carbohydrates). These are also referred as non-cellular portion of plant. Some of the important heteropolysaccharides are:

Hemicellulose: The constituents of hemicellulose are xylose, arabinose, uronic acid, glucose and galactose. It is more digestible than cellulose.

Chitin: It forms the structural element in lower plants and in invertebrates. Its subunits are 2-acetamido-2-deoxy-D-glucopyranose linked by β -1, 4, glycosidic bonds.

Pectin: It is composed of galactouronic acid chain with arabinose, glucose and xylose. It is used in fruit conserving industry.

Gums: The complete hydrolysis of gums yields arabinose, glucose, rhamnose, glucuronic and galacturonic acids. In nature, it occurs in the form of copper and magnesium salt.

Mucilages: According to source, their constituents differ. Mainly composed of arabinose, galactose, rhamnose and galacturonic acid.

Table 2.1: Classification of Carbohydrates

Class (Degree of Polymerization)	Subgroup	Components
Sugars (1-2)	Monosaccharides	Glucose, Galactose, Fructose
	Disaccharides	Sucrose, Lactose, Trehalose
	Polyols	Sorbitol, Mannitol
Oligosaccharides (3-9)	Malto-Oligosaccharides	Maltodextrins
	Other Oligosaccharides	Raffinose, Stachyose, Fructo- Oligosaccharides
Polysaccharides (>9)	Starch	Amylose, Amylopectin, Modified starches
	Non-starch polysaccharides	Cellulose, Hemicellulose, Pectins, Hydrocolloids

2.4 SOURCES OF CARBOHYDRATES

Starch and sugars constitute the main carbohydrates in human diet. Grains and vegetables constitute the primary source of the starch while fruits may contain considerable amount of sugars. Small amount of glycogen is present in the meat and seafood. The common sources of different carbohydrates are as follows:

Monosaccharides: Corn syrup, fruits, honey.

Disaccharides: Sugarcane, sugar beets, milk, germinating cereal grains.

Polysaccharides: Cereal grains, legumes, potatoes and other vegetables, liver, muscle tissues, algae and seaweeds.

Many fruits contain large amounts of organic acids like citric and malic acids. Though these acids are not carbohydrates, they contribute to the total intake because of their rapid conversion to carbohydrates in the body.

Check Your Progress 2

1) What are the main sources of carbohydrates?

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2) Define carbohydrate.

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3) Monosaccharide contains.....saccharide unit.

4) Aldoses are carbohydrates withfunctional group.

2.5 CLINICAL APPLICATIONS OF CARBOHYDRATES

You all learnt how much important is carbohydrate for our body. The carbohydrates should be supplied to body in a continuous manner. Both excess as well as lack of carbohydrates is detrimental for body. There are a number of diseases associated with carbohydrates such as hypoglycemia, lactose intolerance, diabetes mellitus, galactosemia, glycogen storage disease etc. Diseases associated with carbohydrate are given below.

2.5.1 Hypoglycemia

Hypoglycemia means low sugar level in blood.

Symptoms: Nervousness, anxiety, hunger, palpitations and headache.

Causes: Clinicians have identified two types of hypoglycemia and their causes.

- i) **Reactive hypoglycemia:** Reactive hypoglycemia occurs after a meal if persons had abdominal surgery or has diabetes.
- ii) **Fasting hypoglycemia:** Fasting hypoglycemia occurs due to inadequate food or from poor eating habits. Several drugs may cause hypoglycemia e.g., alcohol which blocks glucose production in the liver.

Other clinical conditions which cause hypoglycemia are: (i) Tumors in pancreas stimulate excessive insulin secretion (ii) Adrenal insufficiency: Stress conditions increases metabolic demands of the body and contribute to hypoglycemia which is due to adrenal insufficiency.

Diagnosis: Normal blood glucose range is 70 - 110 mg/100ml. Below 70mg/100ml of blood sugar level is the sign of hypoglycemia.

Treatment: A diet of frequent small meals, rich in complex carbohydrates and a good dietary fiber content with fewer carbohydrates and sugars.

2.5.2 Lactose Intolerance

One of the most common problems throughout the world is lactose intolerance. In this condition, the man is unable to digest product with lactose such as non-fermented milk.

Symptoms: Abdominal cramps, nausea, bloating or diarrhea when milk is consumed.

Cause: The problem is due to deficiency of lactase, a digestive enzyme found in the microvilli of small intestine that converts milk sugar and lactose (by hydrolysis) into its component monosaccharide, glucose and galactose for

absorption. Children are born with high level of lactase to utilize high lactose level in mother's milk. In animals, lactase activity decreases shortly after birth and in human after five years of age.

Diagnosis: Based on symptoms along with history of non-fermented milk consumption.

Treatment: Treatment consists simply cutting down of milk consumption. Most lactose intolerant patients digest fermented milk products (cheese, butter milk, yogurt) very well and they can consume these as their primary source of calcium instead of milk. Low lactose milk and sweet acidophilus milk have been developed for lactose intolerant people.

2.5.3 Diabetes Mellitus

It is a metabolic disorder in which the ability to oxidize the primary fuel glucose is almost lost. It also affects the fat and protein metabolism.

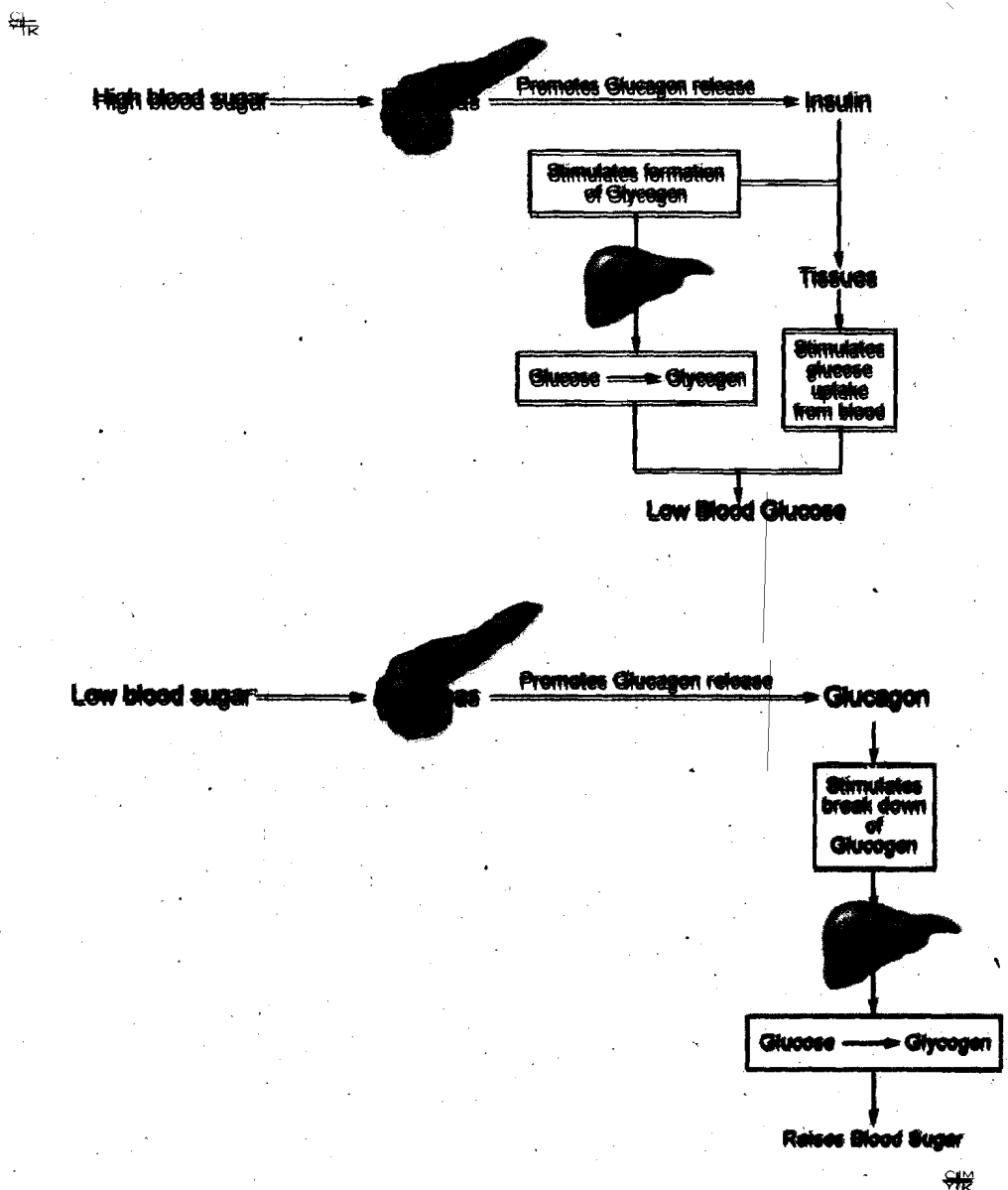


Fig. 2.8: Normal Physiological Functions of Pancreas

Symptoms: Glucose level increases in the blood and is lost in the urine, causing excessive urination, thirst and hunger and on prolonged disease develops multiple system complications.

Cause: Sugar and other simple carbohydrates can contribute to blood glucose level in persons with diabetes. Sugar does not cause diabetes but the cause is due to lack of available insulin, the pancreatic hormone.

Diagnosis: Diagnosis of diabetes can be done by different methods like:

- i) **Estimation of sugar in urine (Glycosuria):** Presence of sugar in urine is detected by colorimetric method.
- ii) **Elevation of blood sugar (Hyperglycemia):** Normal level of blood sugar is 70 - 100 mg/100ml. In diabetes, blood sugar level increases from the normal level.
- iii) **Glucose tolerance test:** In this test, 75 gram dose of glucose is given to patients. The patient is kept on fasting and two hour plasma was collected. The glucose level is estimated. A two hour plasma glucose value of 200mg/100ml or above indicates diabetes and 140 - 200mg/100ml indicates the impaired glucose tolerance.
- iv) **Glycosylated Hemoglobin A1c:** It is a relatively stable molecule within the red blood cells. Higher the level of circulating glucose over the life of the red blood cells, the higher the concentration of glycohemoglobin. It provides an effective tool for evaluating long-term management of diabetes and degree of control.

Treatment and control: Treatment of diabetes includes:

- Well-planned food habits and exercise
- Insulin therapy
- Self-monitoring of blood glucose level
- Nutrient balance: Ratio of carbohydrate, protein and fat in the diet is based on the recommendation of ideal glucose regulation. Majority of carbohydrate in the form of complex carbohydrate, starch should be used. About 50 - 55 per cent of total kilocalorie of the diet is of complex carbohydrates. It gives simple sugars slowly over a time. Fiber rich diet (polysaccharides) also has some effect on blood glucose level.

2.5.4 Other Conditions

Hyperactivity: Greater activity, ease of stimulation and other hyperactive signs suggesting an association of sugar intake and hyperactivity.

Dental caries: Dental caries is the only health problem caused by sugar. Better dental care can greatly reduce the incidence of caries.

Check Your Progress 3

1) What is the level of blood sugar in normal condition and in hypoglycemic condition?

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2) Name any four diseases related to carbohydrates.

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3) What are the symptoms of hypoglycemia?

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4) What is the cause of diabetes?

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5) List the methods of diagnosis of diabetes.

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6) How the diabetes can be controlled?

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2.6 DIETARY FIBERS AND ITS IMPORTANCE

Dietary fibers are also known as crude fibers and these are made of polysachharide. Importance of dietary fibers in body physiology, specially in relation to consumption of meat is discussed below:

2.6.1 Carbohydrate Content of Meat

Meat provides calories from proteins, fats and limited quantities of carbohydrates. It's more vital contributions to diets are derived from protein, B vitamins, certain minerals and essential fatty acids. Carbohydrates constitute less than one per cent of the weight of meat, most of which is present as glycogen and lactic acid. The liver is the main storage site of glycogen. Meats are poor source of carbohydrates except those processed products to which sugars or other carbohydrates have been added.

The lack of carbohydrates content in meat and meat products induces constipation and particularly for old age group. Now-a-days the introduction of dietary fiber in diet and even in meat product formulation is being practiced. Besides reducing the cost, it has various added advantages because of its physiological properties. Some of the physiological properties of dietary fiber along with related effects in body system have been discussed below.

2.6.2 Physiological Properties of Fibers

Dietary fiber includes a variety of polysaccharides. About 15-20g /day of dietary fibers is recommended for health. Different physiological properties are:

Water absorption: Water absorption contributes to bulk forming laxative effect. It influences the transit time of food mass through the digestive tract and further absorption of nutrients.

Binding effects: Binding effect of fibers influences blood lipid levels through their capacity to bind cholesterol and bile salts and prevent their absorption. Excessive dietary fiber has undesirable effect of binding minerals such as iron, zinc or calcium thus preventing needed absorption.

2.6.3 Clinical Association Between Dietary Fiber and Various Diseases

Because of diverse physiological function dietary fibers are useful in various diseases. The effects of fibers in various diseases are listed below:

Table 2.2: Use of dietary fibre during disease condition

Disease condition	Usefulness of dietary fibre
Diabetes mellitus	<ul style="list-style-type: none"> • Reduces fasting blood sugar level • Reduces glycosuria • Reduces insulin requirements • Increases insulin sensitivity
Obesity	<ul style="list-style-type: none"> • Increases satiety rate • Reduces energy density • Reduces nutrient bio-availability • Alters hormonal response and thermogenesis
Coronary heart disease	<ul style="list-style-type: none"> • Inhibits recirculation of bile acids • Reduces triglyceride and cholesterol level
Colon cancer	<ul style="list-style-type: none"> • Reduces incidence of disease
Other gastrointestinal disorders like Diverticular disease, Constipation, Hernia, Hemorrhages	<ul style="list-style-type: none"> • Reduces pressure from within the intestinal lumen • Increases diameter of the intestinal lumen, thus allowing intestinal tract to contract more, propelling contents more rapidly and inhibiting segmentation

Check Your Progress 4

1) Dietary fibers are made up of

2) What are the physiological properties of fibers?

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3) Name the diseases, which can be managed by the intake of fibers?

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2.7 LET US SUM UP

Primary fuel of our body is carbohydrate, which provides energy. Starches and sugars are the basic fuel forms of carbohydrates. Carbohydrates are called “quick energy” foods, they are our major source of energy. Glucose is a major fuel to provide energy. Other forms of carbohydrates are glycogen for storage, ribose in nucleic acid, galactose in lactose of milk, in certain complex lipids and in combination with protein in glycoprotein and proteoglycans. Special functions of carbohydrates in our body are glycogen reserve, protein sparing function, antiketogenic effect, heat action and in central nervous system.

Hypoglycemia means low blood sugar. Normal blood glucose range is 70-110 mg/100ml. Blood sugar level below 70mg/100ml is the sign of hypoglycemia. Control measures of hypoglycemia include frequent small meals at short intervals, rich in complex carbohydrates and good dietary fiber content with fewer carbohydrates and sugars. Lactose intolerance is due to deficiency of lactase enzyme and can be treated by simply cutting down the milk consumption. Diabetes mellitus is a metabolic disorder with high blood sugar level. Treatment of diabetes includes well-planned food habits and exercise, insulin therapy, self-monitoring of blood glucose level and balance nutrient. Main source of carbohydrates are grains, vegetables and fruits. Small amount of glycogen are present in the meat and seafoods.

Carbohydrates or saccharide (Greek: Sacharon, sugar) means “carbon hydrate”. Carbohydrates are classified as monosaccharide, disaccharides and polysaccharides according to the number of basic unit.

Dietary fibers are made up of polysaccharides. Physiological properties of fibers are water absorption and binding effect. Dietary fibers play important role in management of diseases like diabetes, obesity, coronary heart disease, colon cancer and gastrointestinal problems. Meats are poor source of carbohydrates except those processed products to which sugars or other carbohydrates have been added.

2.8 KEY WORDS

Carbohydrates	:	Carbohydrates or saccharides (Greek: Sacharon, sugar) means "carbon hydrate" which is $(CH_2O)_n$ where $n > 3$.
Disaccharides	:	Sugars composed of two saccharide units.
Fasting hypoglycemia	:	Occurs after extended period without food or from poor eating habits.
Galactosemia	:	It is the accumulation of galactose in blood.
Glucose tolerance factor	:	It stimulates the action of insulin.
Hyperglycemia	:	Hyperglycemia refers to an elevated glucose level than normal in blood.
Hypoglycemia	:	Hypoglycemia is the condition when glucose level is below normal in blood.
Lactose intolerance	:	A condition that results in abdominal cramps, nausea, bloating or diarrhea when milk is consumed.
Obesity	:	Clinical term for excess body weight.
Oral hypoglycemic agents:	:	Drugs act to lower the elevated blood glucose by stimulating pancreas to produce more endogenous insulin.
Polysaccharides	:	Made up of many simple sugars.

2.9 SOME USEFUL BOOKS

Williams, S.R. (1990). *Essential of Nutrition and diet therapy*. Times Mirror/Mosby College Publishing.

Williams, E.R. and Caliedo, M.A. (1984). *Nutrition: Principles, Issues and Applications*. McGraw-Hill book company, New York.

2.10 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress 1

- 1) Carbohydrates are known as 'quick energy' foods because they provide energy due to rapid breakdown in the body.
- 2) 50-60 per cent of energy is provided by carbohydrates for normal functioning of body.
- 3) Starch and glycogen are two stored forms of carbohydrates.
- 4) Carbohydrates are the major component of our diet because (a) these are widely available (b) easily grown plants such as grains, vegetables and fruits (c) Carbohydrates are relatively low in cost d) they may be stored easily. Carbohydrate rich foods can be kept in dry storage for relatively longer period without spoilage.
- 5) Special functions of carbohydrates in our body are glycogen reserve, protein sparing function, antiketogenic effect, heart action and in central nervous system.

- 6) (i) **Antiketogenic effect:** High amount of carbohydrate in diet provides sufficient amount of energy. Due to which, there is inhibition of lipid catabolism. The formation of ketone from lipids was inhibited.
- (ii) **Protein sparing function:** The presence of sufficient carbohydrates prevents the conversion of protein to its components which fulfil the energy needs so that the proteins are used in the body for its basic structural purpose of tissue building.
- 7) Glycogen is the emergency source of contractile energy of cardiac muscle.
- 8) Glucose is required for functional integrity of nerve tissue.

Check Your Progress 2

- 1) Main source of carbohydrates are grains, vegetables and fruits. Small amount of glycogen are present in the meat and seafoods.
- 2) Carbohydrates or saccharides (Greek: Sacharon, sugar) means "carbon hydrate" which is $(CH_2O)_n$ where $n > 3$.
- 3) One.
- 4) Aldehyde.

Check Your Progress 3

- 1) Normal level of blood sugar is 70-110 mg/ 100ml and below 70 mg/100ml in hypoglycemia.
- 2) Diseases associated with carbohydrates are hypoglycemia, lactose intolerance, diabetes mellitus and galactosemia.
- 3) The symptoms of hypoglycemia are nervousness, anxiety, hunger, palpitations and headache.
- 4) Diabetes is a metabolic disorder. The cause is the lack of available insulin, the pancreatic hormone.
- 5) Diagnosis of diabetes can be done by different methods: (i) Estimation of sugar in urine (glycosuria), (ii) Elevation of blood sugar (hyperglycemia), (iii) Glucose tolerance test, (iv) Glycosylated Hemoglobin A_{1c}.
- 6) Diabetes can be controlled by well-planned food habits and exercise, insulin therapy, self monitoring of blood glucose level and nutrient balance.

Check Your Progress 4

- 1) Polysaccharides.
- 2) Physiological properties of fibers are water absorption and binding effect.
- 3) Dietary fibers play an important role in management of diseases like diabetes, obesity, coronary heart disease, colon cancer and gastrointestinal disorders.

FOOD GUMS

INTRODUCTION:

Natural gums are polysaccharides of natural origin, capable of causing a large increase in a solution's viscosity, even at small concentrations. In the food industry they are used as thickening agents, clarifying agents, gelling agents, emulsifying agents, and stabilizers. Most often these are botanical gums, found in the woody elements of plants or in seed coatings.

CLASSIFICATION:

Natural gums can be classified according to their origin. They can also be classified as uncharged or ionic polymers (polyelectrolyte).

1. Natural gums obtained from seaweeds:

Polyelectrolytes:

- Agar(E406)
- Alginic acid(E400) and Sodium alginate(E401)
- Carrageenan(E407)

2. Natural gums obtained from non-marine botanical resources:

Polyelectrolytes:

- Gum arabic(E414)
- Gum tragacanth(E413)
- Karaya gum (E416)

Uncharged

- Guar gum(E412)
- Locust bean gum(E410)
- Glucomannan(E425)
- Tara gum(E417)

3.Natural gums produced by bacterial fermentation:

Polyelectrolytes:

- Gellan gum(E418)

Uncharged:

- Xanthan gum(E415)

Agar (E406)

- Agar or agar-agar is a jelly-like substance, obtained from algae.
- Agar forms the supporting structure in the cell walls of certain species of algae(*Gelidium amansii*), and which is released on boiling. These algae are known as agarophytes, and belong to the Rhodophyta(red algae) phylum. Agar is actually the resulting mixture of two components: the linear polysaccharide agarose(70%) and a heterogeneous mixture of smaller molecules called agarpectin(30%)
- Melting point 85°C
- Solidifying range 32°C- 40°C
- Agar-agar is a natural vegetable gelatin counterpart
- Available as dried strips or in powdered form

Alginic acid (E400) and Sodium alginate(E401)

- An anionic polysaccharide distributed widely in the cell walls of brown algae, where through binding with water it forms a viscous gum
- Empirical formula is $\text{NaC}_6\text{H}_7\text{O}_6$

Carrageenan(E407)

- Carrageenans are a family of linear sulphated polysaccharides that are extracted from red edible seaweeds.
- They are widely used in the food industry, for their gelling, thickening, and stabilizing properties.
- Their main application is in dairy and meat products, due to their strong binding to food proteins.
- There are three main varieties of carrageenan which differ in their degree of sulfation. Kappa-carrageenan has one sulfate group per disaccharide, iota-carrageenan has two, and lambda-carrageenan has three.

Gum arabic(E414)

- Gum arabic, (acacia gum), is a natural gum consisting of the hardened sap of various species of the acacia tree.
- Gum arabic is predominantly collected from two related species, namely *Acacia Senegal* and *Acacia seyal*
- Gum arabic is a complex mixture of glycoproteins and polysaccharides. It is the original source of the sugars arabinose and ribose, both of which were first discovered and isolated from it, and are named after it.
- Gum arabic is used primarily in the food industry as a stabilizer.
- It is edible

Gum tragacanth(E413)

- Gum tragacanth is a viscous, odorless, tasteless, water-soluble mixture of polysaccharides.
- Obtained from sap that is drained from the root of the plant (goat's thorn and locoweed) and dried.
- Used in foods as an emulsifier, thickener, stabilizer, and texturant additive.

Karaya gum (E416)

- A vegetable gum produced as an exudate by trees of the genus Sterculia.
- Gum karaya is an acid polysaccharide composed of the sugars galactose, rhamnose and galacturonic acid.
- It is used as a thickener and emulsifier in foods.
- Also used to adulterate gum tragacanth due to their similar physical characteristics.

Guar gum (E412)

- Guar gum is obtained from guar beans which has thickening and stabilizing properties useful in the food industry.
- The guar seeds are dehusked, milled and screened to obtain the guar gum.
- A polysaccharide composed of the sugars galactose and mannose.
- Used in baked goods, dairy products, condiments, soups, instant oatmeal, sweet desserts etc

Locust bean gum (E410)

- A galactomannan vegetable gum extracted from the seeds of the carob tree.
- Used as a thickening agent and a gelling agent in food industry
- Occurs as a white to yellow-white powder.
- Consists chiefly of high-molecular-weight polysaccharides, composed of galactose and mannose units combined through glycosidic linkages.
- The bean, when made into powder, is sweet-with a flavor similar to chocolate.

Glucomannan (E425)

- Glucomannan is a water-soluble polysaccharide that is considered a dietary fiber.
- The component sugars are β -(1-4)-linked D-mannose and D-glucose in a ratio of 1:6:1.
- It is a hemicelluloses component in the cell walls of some plant species.
- Glucomannan is a food additive used as an emulsifier and thickener.

Tara gum (E417)

- Tara gum is a white, nearly odorless powder that is produced by separating and grinding the endosperm of T.spinosa seeds.
- Tara gum consists of a linear main chain of (1-4)- β -D-mannopyranose units attached by (1-6) linkages with α -D-galactopyranose units.
- Used in the preparation of convenience foods, such as ice cream.

Gellan gum (E418)

- Gellan gum is a water soluble anionic polysaccharide produced by the bacterium *Sphingomonas elodea*.
- Consists of two residues of D-glucose and one of each residues of L-rhamnose and D-glucuronic acid.
- It is widely used as a thickener, emulsifier, and stabilizer.

Xanthan gum (E415)

- It is a powerful thickening agent, and also has uses as a stabilizer to prevent ingredients from separating.
- It can be produced from a range of simple sugars (glucose, sucrose or lactose) using a fermentation process.
- Xanthan gum derives its name from the strain of bacteria used during the fermentation process, *Xanthomonas campestris*.
- Used in salad dressings and sauces, ice creams etc.

Functional properties of Proteins

Proteins are made up of a “team of amino acids”. Therefore, the capabilities of the “team” will depend upon the individual capabilities of its players, that is, its amino acids. For example, some amino acids are polar or charged, allowing them to dissolve in water, while others are non-polar, preventing them from dissolving in water. Water-soluble proteins are referred to as *hydrophilic* while those that are not soluble, are called *hydrophobic*. **The functional properties of protein** are affected by their structure. Examples of functional properties include water absorption and retention, solubility, color, gelation, viscosity and texture, emulsification, foam formation, flavor-binding properties, curdling, and enzymatic browning.

Water Absorption and Retention

Proteins that are made up of mostly hydrophilic amino acids will tend to absorb and retain more water. For example, bakery products containing high-protein ingredients such as soy and other pulses will be more moist and heavier due to greater water retention. This is an important functional property for bakers because more water retention means greater product yield and higher profits.

Solubility

Proteins that are made up of mostly hydrophilic amino acids will be more soluble. This is particularly important when you are making beverages. For example, soybean protein and pea proteins are found to be highly soluble in water. This makes them ideal for use in beverages and soups.

Color

Proteins react with reducing sugars to form flavors and color compounds in a process called *Maillard reaction*. The dark colors that you see on the surface of breads, and the grill marks on steak is due to Maillard reaction. For this reason, breads containing milk or soy flour will have a darker color.

Gelation

Some proteins have the ability to form a gel. A prime example of this type of protein is gelatin. Gelatin is made from collagen which is a rope-like protein polymer from the bones and tissue (skin, tendons and ligaments) of animals (usually pigs and cows). When gelatin is heated, it dissolves and is dispersed in solution. But, as it cools, the rope-like strands bond together and trap water between them in the process. This results in the formation of a gel. An example of this would be products made using the Jello-O brand of products from Kraft.

Viscosity and Texture

Proteins can make foods not only more viscous (thicker) as we saw in the formation of gels, but also elastic. We call this property, visco-elasticity. The best example of this is seen in gluten proteins. As water is added to wheat and the mixture molded, a dough is formed. We are able to stretch this dough like an elastic which recoils when it is released. This is an important characteristic that gives bread its texture. As the bread dough rises during fermentation, the strong visco-elastic property of the gluten proteins prevents the bread from collapsing. A higher protein content in breads and bakery products will produce a firmer

texture. Cakes are generally made using wheat with a low protein content (7-9%) to give a soft texture, whereas bread flours have high protein (14-16%) for firmness.

Emulsification

Emulsifiers are substances that are able to prevent the separation of oil and water in food. They are able to do this because part of their structure allows them to interact with water and another part with oil. Therefore they can grab onto both water and oil to form a bridge between them. Many proteins have this property because they contain both hydrophilic and hydrophobic amino acids. For example, milk in ice-cream contributes an emulsification effect by helping to prevent separation of fat and water.

Foam Formation

A food foam is formed when air bubbles are dispersed in water. Examples of food foams are whipped cream, ice-cream, marshmallow, and beaten egg whites. Proteins stabilize foams by forming a protective coat around the air bubbles in the foam, which prevents the bubbles from collapsing. They are able to form this coat because of their hydrophilic/hydrophobic nature. The hydrophilic part of the protein will bind water and the hydrophobic part will bind with the air, creating a stable bridge.

Flavor-Binding

Proteins are generally odorless compounds on their own, but they can bind flavor compounds and therefore impart new flavor to foods. I have observed this in my study looking at the flavor profile of bean flour fractions. What I have found is that flour fractions with more protein, have a more diverse range of flavor compounds, and these are present at very high concentrations. The ability of proteins to bind flavors can have a negative impact on the flavor of end-products if off-flavors are trapped. On the positive side, manufacturers can use this property to trap and retain certain flavor ingredients in food.

Curdling

Proteins can coagulate with the addition of acids. For example, in my research, I am able to separate bean protein from other components of bean flour by adding acid to the flour slurry. At a pH of 4.6, proteins in the slurry curdle and fall out of solution. The point at which proteins precipitate or fall out of solution, is called the *isoelectric point*. It is a point where the charge on the protein changes to neutral. At a neutral charge it is no longer capable of dissolving in water. The same principle is followed in the production of yogurt and cheese. For example, lactic acid bacteria produce lactic acid, in cheese making resulting in curdling of milk and the production of milk curds which can then be fermented into cheese.

Enzymatic Browning

Maillard reaction is called *non-enzymatic browning* since it is not dependent on the work of enzyme. Remember that with Maillard browning you need only proteins and reducing sugars. Another type of browning is called *enzymatic browning*. That is when browning is caused by *enzymes*. Enzymes are proteins that speed up the rate of chemical reaction in living systems. One type of reaction that they speed up is the browning reaction. This reaction is caused by the action of the enzyme *poly phenol oxidase* on *phenol* compounds in foods, in the presence of oxygen. The result is a brown compound called *melanin*. This reaction is evidenced in apples and potato after they are cut and left exposed to oxygen.

Functional properties of lipids

Fats and oils may come from vegetable or animal source. Vegetable sources include coconut, palm, olive, peanut, corn, safflower, sunflower, cottonseed, and soybean oil. Animal sources include butter (from dairy), lard (from pork), tallow (from beef) and fish oil. Fats and oils provide a high source of energy and is used in the making of important bio-compounds such as cell membrane and non-protein hormones. They are also important in digestion of fat-soluble vitamins (A, D, E and K). Functional properties of fats and oils are described below.

Heat Transfer

Due to their low specific heat capacity and high boiling point, fats and oils can heat up quickly and reach very high temperatures. This allows them to be used in frying. High frying temperatures enables the development of brown colors and new flavors due to caramelization and Maillard reaction. At elevated temperatures, fats and oils smoke. This is called the **smoke point**. They say that where there is smoke there is fire so watch out. Continued heating beyond the smoke point will lead to ignition of the oil. This is called the **flash point**. Oil that has been abused to its smoke point should be thrown out due to the development of harmful breakdown products called **free-radicals**.

Flavor retention

Most flavors are hydrophobic in nature, making fats and oils a good solvent for them. Hence foods that are fatty will taste better compared to low-fat foods which are generally bland. Consider the difference in flavor between skimmed milk and whole milk for example. Or, compare meats that have high marbling (i.e. high fat) versus those that have low marbling. The greater the marbling the more flavorful and desirable the eating quality.

Texture

Fats and oils improve not only flavor but also texture. Their ability to lubricate materials generate a juicy and tender mouthfeel. In food processing, shortenings texturize pastry by trapping tiny air bubbles during mixing, which then expand with heat to aerate and soften the final product. In addition, shortening can create flaky textures when layered between thin sheets of dough. Fats can produce different textures due to the combination of fat crystal forms they contain. The three crystal forms are alpha (α), beta prime (β'), and beta (β) crystals. Alpha crystals are formed by rapid cooking of fat and are the most unstable crystals with the lowest melting point (54.7°C). β' crystals are more stable and have a higher melting point (63.2°C). They are produced when cooled at a slower rate compared to α crystals. Shortening and margarine are high in β' crystals and are excellent for creaming. β crystals are formed during even slower cooling than β' crystals. They are most stable with a high melting point (73.5°C). The firmness of chocolate is due to the presence of high β crystals. Ultimately the type of crystal forms are dependent on the type of fatty acid present in the fat or oil.

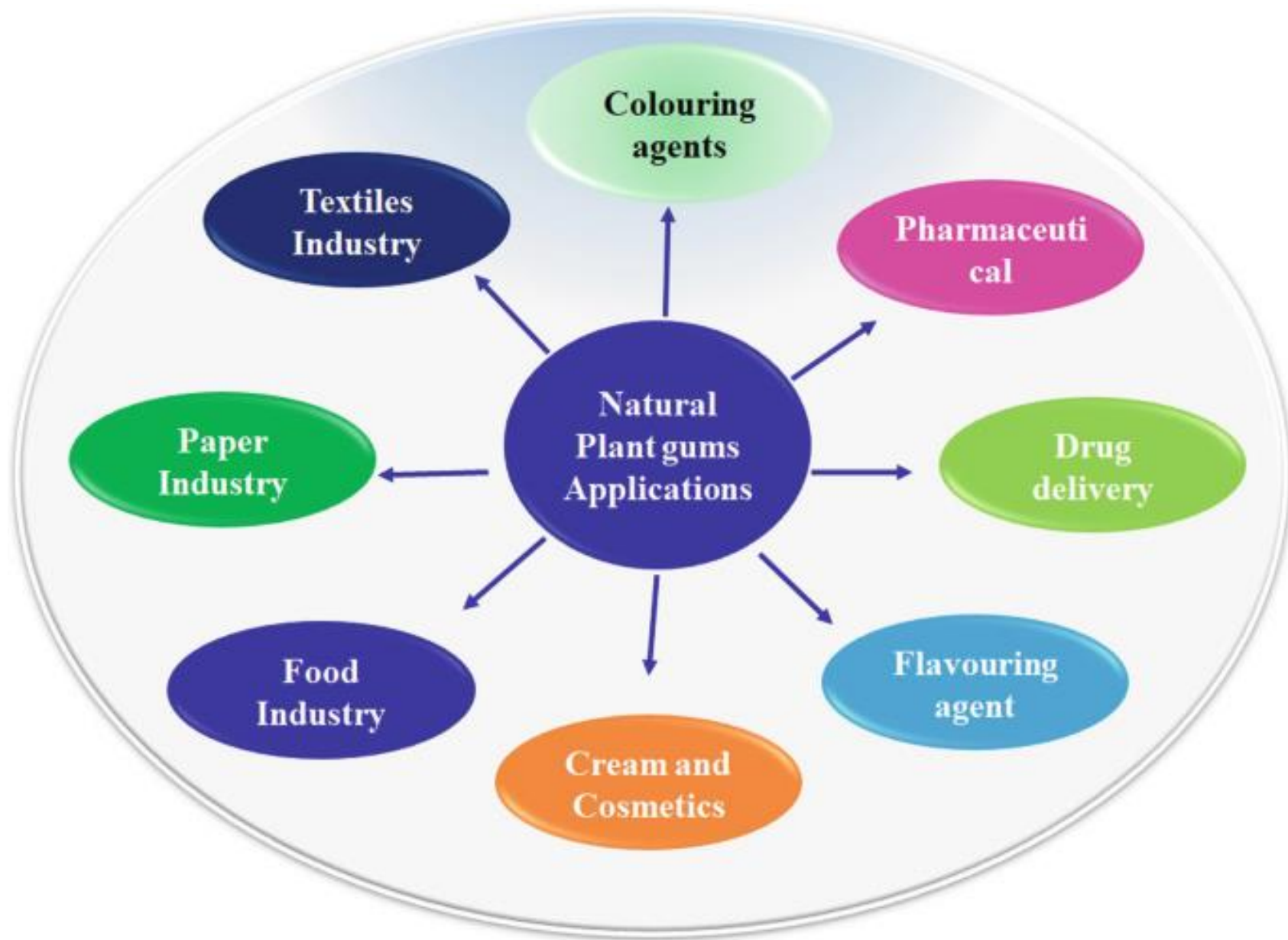
GUMS

- Gums are formed primarily due to the disintegration of plant cellulose
- Gums Polysaccharide in origin
- Natural cementing substance between cells
- Found as decomposition product
- Exude naturally from stem, root or leaves due to wound or burns
- Commercial gums in form of dried exudation



Properties

- **Colloidal in nature**
- **Form dry exudates**
- **Increase viscosity of solution**
- **Either water soluble or can at least imbibe in water**
- **Required heat application for solubility**
- **Insoluble in organic solvents**



uses

- **Confectionery** lollipops, chocolates, jelly beans, pastilles, and others to prevent crystallization
- **Salad dressing and frozen product thickeners and emulsion stabilizer**
- **Dehydrated product protecting important product compounds vit c anthocyanins, and improve stability**
- **Microencapsulants for colour, flavor, and oils in wine clarification**
- **Flavor fixation and emulsifiers in beverages and meat product**

- **In textile industry for sizing and finishing**
- **In paper industry as adhesives and stabilizers**
- **Used in polishes, contact insecticides, pesticides**
- **Preparation of powdered stable, oils soluble vitamins**
- **Relaxation of ulva and throat**
- **Used in pharmaceuticals**

classification

- Natural gums can be classified according to their origin
- They can be classified as uncharged or ionic polymers

1. Natural gums obtained from seaweeds: Polyelectrolytes

Agar(E406)

Alginate(E400) and Sodium alginate(E401)

Carrageenan(E407)

2. Natural gums obtained from non-marine botanical resources: Polyelectrolytes:

Gum arabic(E414)

Gum tragacanth(E413)

Karaya gum (E416)

Uncharged

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Glucomannan(E425)

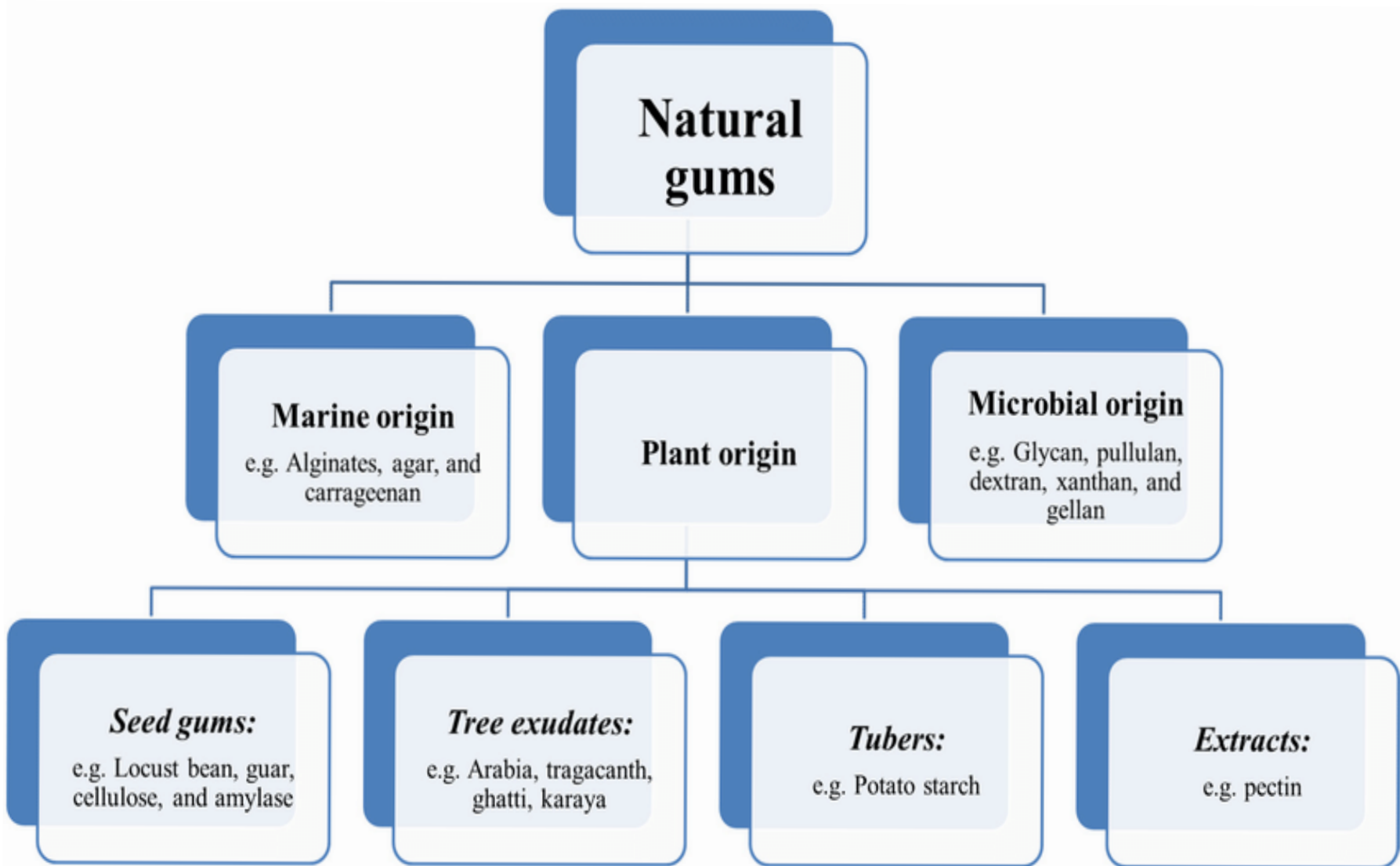
Tara gum(E417)

3. Natural gums produced by bacterial fermentation: Polyelectrolytes

Gellan gum(E418)

Uncharged:

Xanthan gum(E415)



Name	Obtained from	uses
agar	algae(<i>Gelidium amansii</i>)	used in the culture and detection of pathogens from contaminated food and water
Alginic acid and sodium alginate	cell walls of brown algae	used to coat fruits and vegetables, gelling, stabilizer
carrageenan	red edible seaweeds.	used in the food industry, for their gelling, thickening, and stabilizing properties. Their main application is in dairy and meat products, due to their strong binding to food proteins.
Gum arabic	Acacia Senegal and Acacia seyal	a stabilizer.
Gum tragacanth	sap that is drained from the root of the plant (goat's thorn and locoweed)	emulsifier, thickener, stabilizer, and texturant additive.
Karaya gum	exudate by trees of the genus <i>Sterculia</i> .	thickener and emulsifier in foods
Guar gum	guar beans	thickening and stabilizing properties useful in the food industry Used in baked goods, dairy products, condiments, soups, instant oatmeal

Locust bean gum	extracted from the seeds of the carob tree.	thickening agent and a gelling agent
Glucomannan	Konjac plant or elephant yam	food additive used as an emulsifier and thickener.
Tara gum	endosperm of T.spinosa seeds	preparation of convenience foods, such as ice cream.
Gellan gum	bacterium sphingomonas elodea.	thickener, emulsifier, and stabilizer
Xanthan gum	strain of bacteria used during the fermentation process, xanthomonas campestris.	powerful thickening agent stabilizer to prevent ingredients from separating Used in salad dressings and sauces, ice creams etc

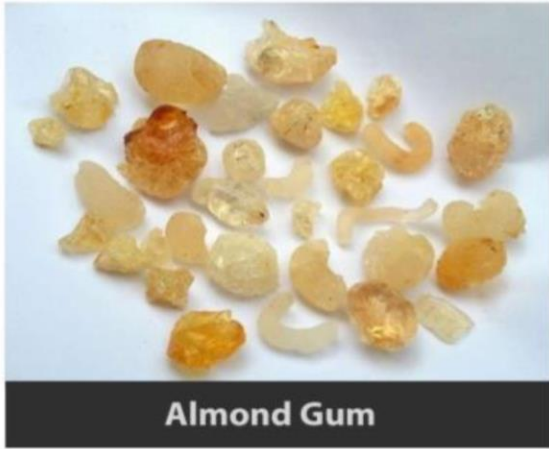


Gum Tragacanth (Flake type)

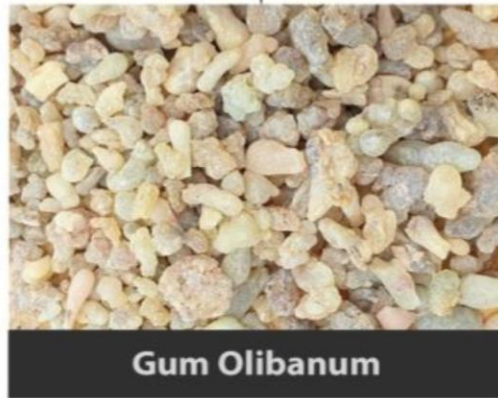


Gum Tragacanth (Ribbon type)

Plant-based gums



Almond Gum



Gum Olibanum



Gum Arabic

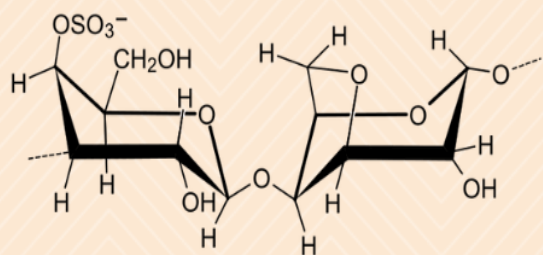
What is agar?

- The gelling agent is an unbranched polysaccharide obtained from the cell walls of some species of red algae, primarily from the genera *Gelidium* and *Gracilaria*, or seaweed (*Sphaerococcus euchema*).

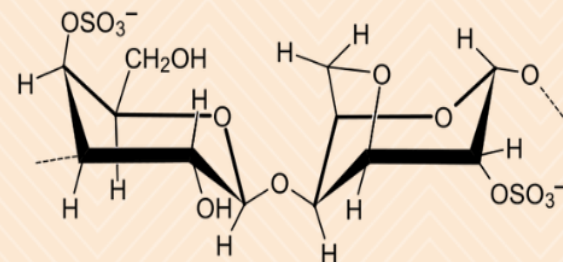


Carrageenan

Carrageenan is a polysaccharide extracted from red seaweed used as a thickening and gelling agent.

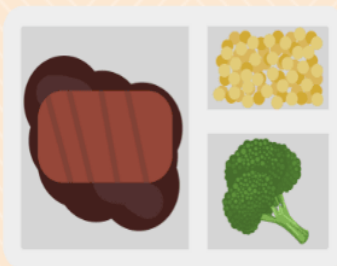


κ -carrageenan



ι -carrageenan

It occurs in many products, especially dairy, meat, and processed foods.





Alginic acid and sodium alginate
obtained from brown algae



Gum arabica from acaica



Guar gum extracted by cluster bean



Glucomannan gum
Extracted by konjac plant



Karaya gum from trees of the genus Sterculia.



Locust bean gum from seeds of the carob tree.



Tara gum obtained from endosperm of *T.spinosa* seeds



Gum tragacant plant (goat's thorn and locoweed)

Thank you

UNIT 7 PROTEINS AND ENZYMES

Structure

- 7.0 Objectives
- 7.1 Introduction
- 7.2 Occurrence of Proteins
 - 7.2.1 Plant Sources
 - 7.2.2 Animals Sources
 - 7.2.3 Microbial Sources
- 7.3 Classification of Proteins
 - 7.3.1 Classification on the Basis of Shape and Size
 - 7.3.2 Classification on the Basis of Products of Hydrolysis
 - 7.3.3 Classification on the Basis of Biological Functions
- 7.4 Structure of Proteins
 - 7.4.1 Amino Acids
 - 7.4.2 Peptides
 - 7.4.3 Structural Organization of Proteins
- 7.5 Properties of Proteins
 - 7.5.1 Physico-chemical Properties of Proteins
 - 7.5.2 Functional Properties of Proteins
 - 7.5.3 Food Applications of Protein Concentrates, Isolates and Hydrolysates
- 7.6 Enzymes
 - 7.6.1 Nomenclature and Classification of Enzymes
- 7.7 Enzyme Utilization in Food Industry
 - 7.7.1 Immobilized Enzymes
 - 7.7.2 Enzymatic Browning
- 7.8 Let Us Sum Up
- 7.9 Key Words
- 7.10 Terminal Questions
- 7.11 Answers to Check Your Progress
- 7.12 Answers to Terminal Questions
- 7.13 Some Useful Books

7.0 OBJECTIVES

After studying this Unit, we shall be able to:

- define proteins and enzymes;
- describe the composition of proteins and enzymes;
- classify proteins and enzymes into different types;
- enumerate the properties of proteins and enzymes; and
- describe the role of proteins and enzymes in food industry.

7.1 INTRODUCTION

In the previous Unit, you learnt about carbohydrates as important constituents of food and their significance in food industry. Another very important constituent of food, proteins are found in all cells and in almost all parts of cell. They contribute to almost half of the body dry weight. Proteins are major organic constituents of protoplasm and a number of extra cellular components. These are important dietary constituents and perform a wide range of functions like providing structure to the body, transporting oxygen and other substances

within an organism, regulating the body chemistry etc. Proteins are essential not only as constituents of food but they also have a significant role to play in the processing and preparation of food. This is primarily due to their water binding capacity and ability to coagulate on heating, Proteins find applications as gel formers, emulsifiers and foaming agents etc. This Unit deals with the classification, structure and properties of proteins along with their role in food processing and preparation.

You know that enzymes are also proteins, and they work as catalysts in carrying out the biological reactions. Several enzymes like amylase, invertase, pectinases, proteases etc. find applications in food processing. It is important to learn about the various classes of enzymes and their role in food processing. These aspects are also dealt with in this Unit.

7.2 OCCURRENCE OF PROTEINS

The term protein was coined by Dutch chemist G.T. Mulder in 1839 on the suggestion of Swedish chemist Jons J Benzelius.

The term protein originates from the Greek word *πρωτεος* (proteios), meaning *of first importance*. These biomolecules are of a large variety and of different sizes and structures. All of these are made up of repeating units or **blocks** of amino acids. You will read about amino acids in Sec.7.4. All proteins contain carbon, hydrogen, oxygen, nitrogen and sulphur. Some of them contain small amounts (< 1%) of phosphorus and some a small quantity of iron, copper, or manganese. Generally, a protein has approximately the following composition.

Carbon, 53%; Hydrogen, 7%; Oxygen, 23%; Nitrogen, 16%; and Sulfur, 1%

Proteins constitute most of the nuclear materials of cells and occur in dried seeds of plants more than in plant tissues. The three main sources of proteins include plants, animals and microbes. Let us read where from we get proteins under these categories.

7.2.1 Plant Sources

Gluten: is a protein found in flour, which forms during bread making. The gluten forms network that traps CO₂ created by yeast, giving bread its characteristic texture and air bubbles.

Plant sources of proteins include cereals, lentils/pulses (*dals*), nuts and oil seeds besides small quantities from vegetables. Cereals like wheat and rice are important sources of protein and are the staple foods of the populations in India. On average, wheat has 12-13% protein while rice has 7-9% protein. Gluten proteins are responsible for the unique bread making property of wheat. Legumes (pulses) and oil seeds are major sources of vegetable proteins. The fresh vegetables do not contain a good amount of protein. The average protein content of the major pulses, oil seeds and some fresh vegetables is given in Table 7.1.

Besides, nuts like cashew nuts, almond nuts, coconuts; walnuts, etc. are the excellent sources of proteins.

Table 7.1: Protein Content of some Pulses, Oilseeds and Fresh Vegetables

		Name	Protein (%)
Dals and Pulses	1	Bengal gram dal	20.8
	2	Black gram dal	24.6
	3	Green gram dal	24.5
	4	Lentil	25.1

		Name	Protein (%)
	5	Dry bean	24.9
	6	Dry pea	19.7
Fresh vegetables	7	Fresh bean	2
	8	Fresh pea	6
	9	Carrot	1
Oilseeds	10	Ground nut	26.7
	11	Soybean	43.2
	12	Sesame	18.3
	13	Cotton seed	19.5
	14	Sunflower seed	12.5

7.2.2 Animal Sources

Proteins are found in animal tissues like muscle, offal and blood. The dietary sources of animal proteins include milk, egg, fish, poultry and meat. The amount of protein in these foods is given in Table 7.2.

Table 7.2: Protein Content of Some Animal Foods

S.No.	Source	Protein (%)
1	Meat	18-22
2	Milk	3.5
3	Egg white	12
4	Fresh water fish	13-25

The animal proteins have a shorter storage life and therefore plant protein foods are consumed in greater amounts as compared to animal protein foods.

7.2.3 Microbial Sources

The proteins are also obtained from microbial sources, i.e. algae, fungi, bacteria, yeast etc. These are termed as single cell proteins (SCP) and are isolated from microorganisms. The isolation of proteins from microorganisms is a cost effective process with good yield.

The term SCP was coined by Prof. Caroll Wilson in 1966.



Fig. 7.1: Various sources of proteins

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) Arrange the following foods in the increasing order of their protein content.
Spinach, lentils, soybean, pulses, fresh beans, carrots, milk

.....
.....

7.3 CLASSIFICATION OF PROTEINS

Proteins have wide structural and functional diversity. It is difficult to classify these on the basis of a single property or a characteristic. However, following are some common basis of classifying them.

- Shape and structure
- Products of hydrolysis
- Biological functions

Let us understand each of these in the following subsections.

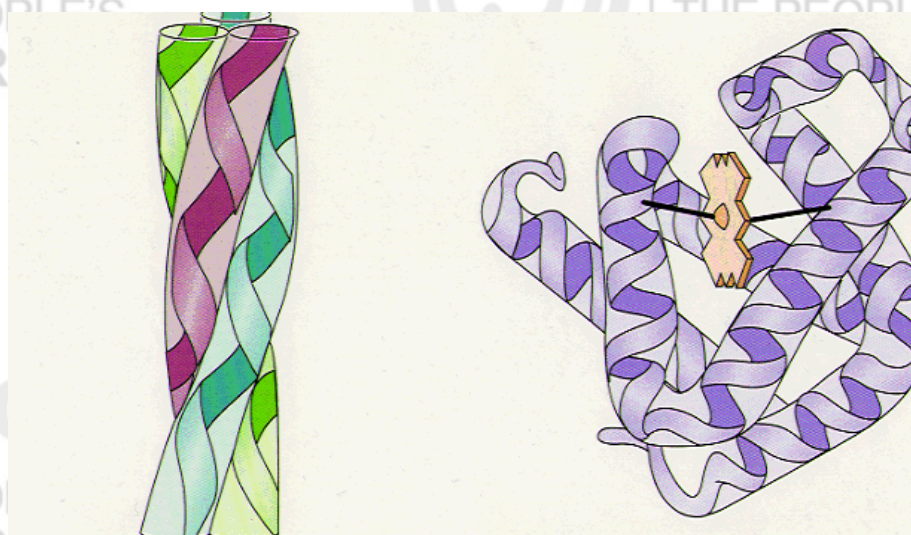
7.3.1 Classification on the Basis of Shape and Size

On the basis of their composition, proteins get different shapes and size which give an indication of their various functions. These can be broadly put into two classes on the basis of their overall shape. These are as follows:

Globular proteins: These contain compactly folded coils of polypeptide chains giving them shape of spheroids or ellipsoids. Examples of this type are albumins, globulins, histones, protamines etc.

Fibrous proteins: This class of proteins looks like fibres or threads. These are insoluble in water and aqueous solutions of acids and bases. These have high mechanical strength. Keratins in hair, actins and myosin in muscles and collagen are examples of this type of protein.

Structures of myoglobin and collagen are shown in Fig.7.2 representing the shape of fibrous and globular proteins respectively.



(a) Collagen

(b) Myoglobin

Fig. 7.2: Structures depicting fibrous and globular proteins respectively

7.3.2 Classification on the Basis of Products of Hydrolysis

On the basis of the products obtained on hydrolysis, proteins can be classified into three categories viz., simple proteins, conjugated proteins and derived proteins.

Simple proteins: Simple proteins are those which are made of amino acid units, each joined by a peptide bond. Upon hydrolysis they yield only a mixture of amino acids. Following are some of the types of simple proteins.

Table 7.3: Types of Simple Proteins with their Examples

S.No.	Type	Examples
1.	Albumins	Egg albumin, serum albumin, lactalbumin
2.	Gliadin	Tissue globulin, serum globulin
3.	Gliadins	Wheat gliadin, hordein (barley) etc.
4.	Albuminoids	Keratin of hairs, skin, egg shell and bones, elastin, collagen of tendons, ligaments and bones.
5.	Histones	Globin of haemoglobin
6.	Protamine	Salmine from the spermatozoa of salmon fish

Conjugated Proteins: Conjugated proteins are composed of simple proteins combined with non protein substances. The non protein substance is called **prosthetic group** or **cofactor**. Following are some of the types of conjugated proteins.

Table 7.4 Types of Conjugated Proteins and their Examples

S.No.	Types	Example
1.	Chromoproteins	Haemoglobin, in which the prosthetic group is iron
2.	Phosphoproteins	Casein in milk and vitellin in egg yolk containing phosphoric acid as prosthetic group
3.	Lipoproteins	HDL (high density lipoprotein), LDL (low density lipoprotein) and VLDL (very low density lipoproteins), have lipids as the prosthetic groups
4.	Glycoprotein	Ovomucoid of egg white containing a carbohydrate moiety
5.	Nucleoproteins	Ribosomes and viruses contain nucleic acids
6.	Metalloproteins	Alcohol dehydrogenase- a Zn containing enzyme
7.	Mucoproteins	Follicle stimulating hormone, β -ovomucoid

Derived Proteins: These are not naturally occurring proteins and are obtained from simple proteins or conjugated proteins by the action of enzymes and chemical agents, heat, mechanical shaking, UV or X-rays.

It includes the following types:

1. **Primary** e.g., myosin, fibrin
2. **Secondary** e.g., peptones, peptides, proteoses etc.

7.3.3 Classification on the Basis of Biological Functions

The involvement of proteins in different functions also makes it a basis for their classification. The different classes along with the functions performed and examples are summaries in Table 7.5.

Table 7.5: Types of Proteins on the Basis of Functions Performed

S.No.	Type	Function	Example
1	Enzymes	Catalytic activity	Kinases, dehydrogenases
2	Storage proteins	Store amino acids	Myoglobin, ferritin
3	Regulatory proteins	Coordinate body activities	Insulin, glucagons

S.No.	Type	Function	Example
4	Structural proteins	Give support and structure	Keratin, collagen
5	Defensive/Protective proteins	Protect against diseases	Immunoglobulins, antibodies
6	Transport proteins	Facilitate import of nutrients into cells or releases of toxic products into surrounding medium	Haemoglobin
7	Contractile and Mobile proteins	Participate in contractile processes e.g. movement of muscles	Actin, myosin

Emulsoids and Suspensoids

In yet another way, the proteins are classified on the basis of their precipitation as emulsoids and suspensoids. **Emulsoids** are those proteins which stay in solution with lot of bound water and are not coagulated by mild acid. On the other hand, the **suspensoids** are those proteins that stay suspended due to the repulsion between charges. These are coagulated at their isoelectric point or by the charge neutralization. Milk is a good example as it contains both of these types. On mild acidification (pH = 4.7-5.3), the casein (suspensoid) separates out and the other proteins remain in the solution and can be separated by filtration. These are called milk serum or **whey** proteins and contain a number of proteins like lactoalbumin and lactoglobulin etc. These may be further separated by salting out with ammonium sulphate or magnesium sulphate.

Check your understanding of the classification of proteins by answering the following questions.



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) Fill in the blanks spaces with appropriate words.
 - i) The compact and folded structures of proteins are put into the category of proteins whereasproteins have a thread like structure.
 - ii) Proteins which give support to the tissues are calledproteins.
 - iii) Haemoglobin is an example of a protein.
 - iv) Proteins obtained as a result of hydrolysis of proteins by the action of chemical agents, heat etc. are calledproteins.

7.4 STRUCTURE OF PROTEINS

It was mentioned in Sec.7.2 that structurally proteins are polymers of α - amino acids which join together through peptide bonds. These polymeric molecules acquire different arrangements depending on their composition and the nature of amino acids constituting them. These arrangements are stabilized with the help of different types of interactions. The protein structure can be understood in terms of four hierarchical levels. Let us learn about amino acids, their

combination to give peptides and proteins and the structure of the proteins so obtained.

7.4.1 Amino Acids

Amino acids are organic molecules and as the name suggests, an amino acid consists of an **amino group** and a **carboxyl group**. The carbon atom which has these two groups attached to it has a hydrogen atom, and a distinctive R group (called side chain) bonded to it. This carbon is called the **α -carbon** because it is adjacent to the carboxyl group. The general formula of an α -amino acid can be represented as shown in Fig. 7.3.

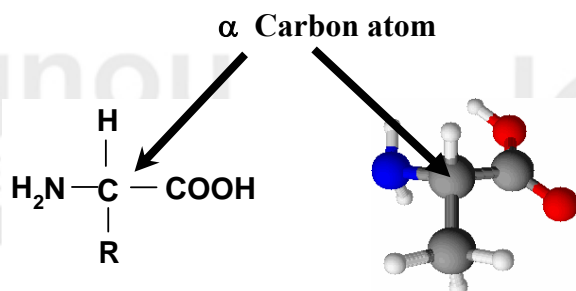


Fig. 7.3: General structure of an α -amino acid

More than twenty natural amino acids are known. Different amino acids contain different side chains i.e., -R groups, varying in size, shape, charge, hydrogen-bonding capacity and chemical reactivity.

Essential and Non-essential Amino Acids

On the basis of their source in the living system, the amino acids are classified into essential and non-essential amino acids. Of the twenty standard amino acids, in case of humans, more than half of these can be made by the body itself, while the others must come from the diet. The former are called the **non-essential amino acids** and the latter are called the **essential amino acids**. The essential amino acids (for human beings) are isoleucine, leucine, valine, lysine, methionine, phenylalanine, threonine and tryptophan. The classification of an amino acid as essential or non-essential does not reflect its importance as all the twenty amino acids are necessary for normal functioning of the body. It simply reflects whether or not the body is capable of synthesizing a particular amino acid. The requirement of essential amino acids per kilogram of the dietary protein is called the **reference pattern** of the amino acids and acts as a standard to determine the quality of the protein being consumed.

The requirement of essential amino acids (g per kg dietary protein)

Isoleucine :	42
Leucine :	48
Lysine :	42
Methionine :	22
Phenylalanine:	28
Threonine:	28
Tryptophan:	14
Valine:	42

7.4.2 Peptides

Two or more, similar or different amino acids combine to give a condensation product with elimination of a water molecule. The product is called the **peptide**. The amide linkage joining the carboxyl group of one amino acid to the amino group of another amino acid is called a **peptide bond**. Two amino acids join to form a di-peptide, three form a tri-peptide, four form a tetra-peptide and so on. Accordingly, these contain one, two, three and more number of peptide bonds. The reaction showing the formation of a peptide is given below.

In a peptide, the amino acid whose carboxyl group participates in the formation of the peptide bond has a free amino group, and is called as the **N-terminal** of the peptide. Correspondingly, the amino acid with a free carboxyl group is called the **C-terminal** of the peptide. The N-terminal is conventionally written to the left while the C-terminal is written to the right.

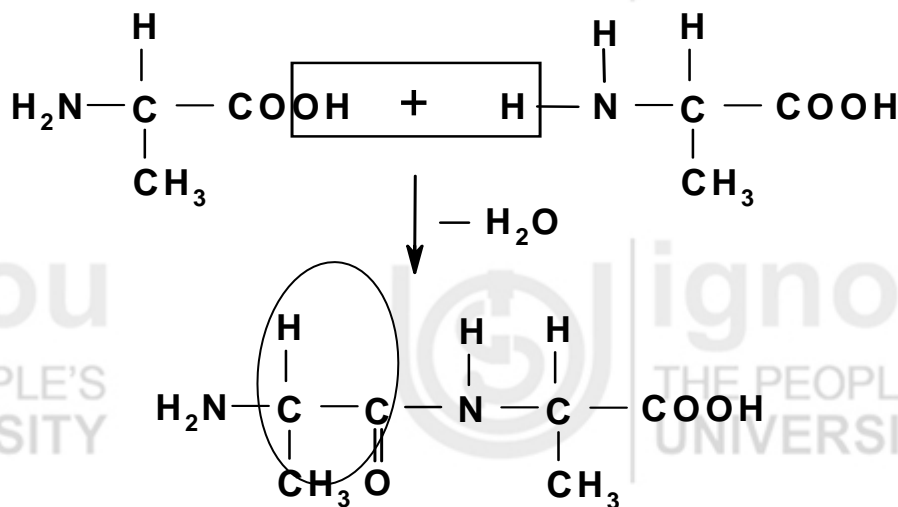


Fig. 7.4: Formation of a Peptide Bond

The number of amino acids in a peptide may vary from 2 to hundreds. Peptides containing 3-10 residues are called **oligopeptides**. When the number is very large then it is called a **polypeptide**. A polypeptide with more than say about 50 amino acids is called a protein. You shall read in the next subsection about the structure of proteins.

7.4.3 Structural Organization of Proteins

The wide variety of functions performed by proteins is due to the possibility of formation of a large number of proteins from a given number of amino acids. The large polymeric molecules of proteins acquire intricate three-dimensional structures. The structural organization of proteins can be seen at four levels. These are, primary (1°), secondary (2°), tertiary (3°) and quaternary (4°) structures. These are explained below:

The complete covalent structure of the polypeptide constitutes its primary structure.

Primary structure: The primary structure of a protein is the sequence of amino acid residues in a completely assembled polypeptide chain. The chain begins with the first amino acid residue at the N-terminal end and progresses in sequence to the last amino acid at the C-terminal end. The primary structure of a protein contains all the necessary information required for the manifestation of higher levels of a three dimensional structure.

Secondary structure: The secondary structure of a protein is related to the way in which the chain of amino acids either twists, folds back upon itself to form a helical, sheet like or a random arrangement. The first two are respectively called the **α -helix** and the **β -pleated sheet** structures. The α -helix and the β -pleated sheet structures are characteristic of fibrous proteins like keratin, silk fibroin or collagen. The secondary structures of proteins are shown in Fig.7.4.

Tertiary Structure: The tertiary structure of the protein refers to the overall three dimensional structure of the protein. The secondary structures of different regions of the polypeptide chain put together give an overall shape to

the polypeptide. This is called the **native structure** of the protein. In this tightly folded structure, the side chains of the amino acid residues with polar groups are exposed to the surface and non-polar groups are buried inside. The stability of the tertiary structure is maintained by hydrogen bonds, attraction between positively and negatively charge side groups, van der Waal forces, and polar and non-polar associations.

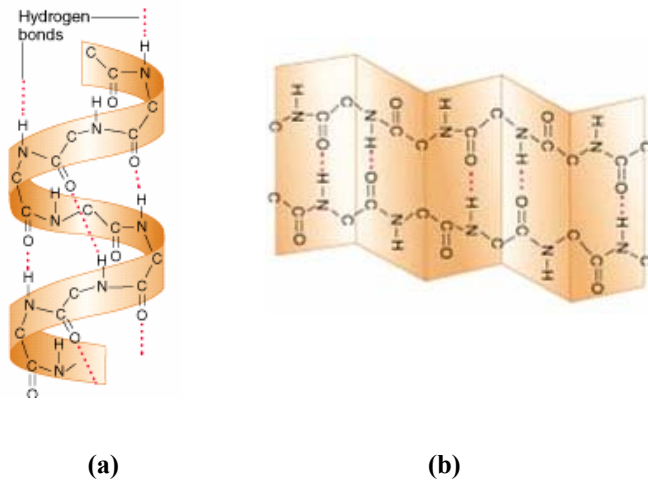


Fig. 7.5: Secondary structures of proteins (a) α -helix, (b) β -pleated sheet

Quaternary Structure of Proteins: Many proteins exist naturally as aggregates of two or more polypeptide chains. Each of these polypeptides is usually folded into an apparently independent conformation. These aggregated structures are called as quaternary structures of the proteins. Structure of haemoglobin depicting the quaternary structure of proteins is given in Fig. 7.6.

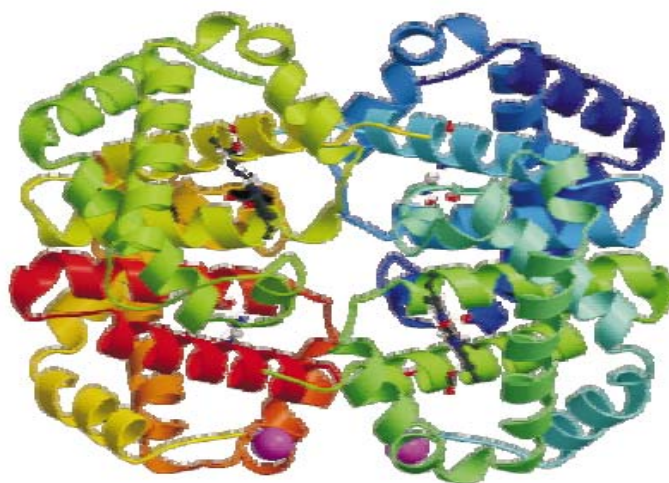


Fig. 7.6: Structure of haemoglobin showing the quaternary structure of proteins

Check your understanding about the structure of proteins by answering the following exercise.

✍ 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) Essential amino acids are called so because

i) These are essential for the growth of the body.

.....

ii) The body cannot synthesize them and have to be taken in diet.

.....

iii) These are essential for the synthesis of proteins.

.....

iv) These are included in the list of 20 amino acids.

.....

2) Match the contents of column A and column B correctly.

Column A

- i) Sequence of amino acids in protein
- ii) Polypeptide with three peptide bonds
- iii) Combination of two or more polypeptides in protein

Column B

- i) Quaternary structure of protein
- ii) Primary structure of protein
- iii) Tetrapeptide

Electrophoresis: The migration of charged colloidal particles or molecules through a solution under the influence of an applied electric field usually provided by immersed electrodes.

7.5 PROPERTIES OF PROTEINS

The properties of the proteins depend on the composition and the structure of the protein. You have already learnt that the side chains of the amino acids constituting the protein vary a great deal in terms of their nature and functional groups. The properties of proteins are therefore related to how these groups are arranged in proteins. The main physico-chemical properties are discussed below:

7.5.1 Physico-chemical Properties

Isoelectric point (pI)

As you are aware, the amino acids and therefore the proteins can act both as acids or bases, they are said to be **amphoteric** in nature. Due to the presence of charged groups they have an ability to migrate in presence of an electrical

field. The nature and number of charges depend upon the pH of the medium and at a specific pH, the protein exists in an electrically neutral (zwitterions) form. This pH is known as **isoelectric point** or **pI** of the protein. Since at this pH the protein has an equal number of positive and negative charges, the net charge of the protein is zero. Therefore, the protein does not move to either electrode when placed in an electric field. At a pH lower than the **pI** the protein would move towards cathode while at a pH greater than **pI** it would move towards the anode. Since the charges on different proteins at a given pH are different, these can be separated in a process called **electrophoresis**.

Solubility

Solubility of proteins is influenced by the nature of solvent, pH, temperature, etc. Globular proteins are generally more soluble in aqueous medium in comparison to elongated fibrous proteins such as keratins. Insolubility of proteins is directly related to its denaturation i.e. aggregation. Aggregation, in turn, influences the effectiveness in food processes like gelation, emulsification and foaming.

Precipitation

Proteins may be precipitated without getting denatured at isoelectric pH, in presence of salts of heavy metals or in presence of a nonpolar solvent like chloroform. In the process, the electrostatic attraction between the ions of proteins gets enhanced and thus facilitating their aggregation and precipitation.

Let us now see how the physicochemical properties of proteins influence their functional properties and contribute to the desirable properties of food.

7.5.2 Functional Properties of Proteins

You are aware that the functional properties of the food constituents refer to their attributes that make them useful for the food besides being nutritionally important. These are the physico-chemical properties which influence the characteristics of foods, e.g., texture, taste, appearance, etc. Emulsification, viscosity, formation of foams and gels, binding to fats or water molecules etc. are some of the functional properties of proteins. An understanding of these properties helps the food technologist to improve the appearance, taste and texture of the food by exploiting them.

These properties are related to the surface properties of the proteins or are the result of the interaction of proteins with its own molecules or water molecules. Accordingly, the functional properties of proteins are classified into the following three categories.

- Hydration properties : related to protein-water interaction.
- Structure formation properties : related to protein-protein interaction.
- Surface properties : related to protein-interface interaction.

Hydration Properties (protein-water interactions)

We know that most of the foods are hydrated to some extent and the behaviour of the proteins in it are influenced by the presence of water and water activity. A number of the properties of proteins like swelling, solubility, precipitation, viscosity, gel formation etc. are related to the interaction of protein molecules with water molecules. These are collectively referred to as the **hydration**

properties. The hydration takes place in a sequence of steps and is said to be progressive in nature. Different hydration properties like water absorption, swelling, wettability, water retention, viscosity and solubility are dependent on the extent of hydration. Highly soluble proteins find applications where emulsification and whipping etc. are important. Soluble protein powders with high initial water absorption capacities give relatively high viscosities and find application in fluid foods like beverages, soups, sauces and creams.

The denatured protein molecules can aggregate to form an ordered network called a **gel**. This is a result of a balance between protein-water and protein-protein interactions. These gels can hold other food ingredients and find applications in preparation of yogurt, tofu and bread dough etc. The gelation of proteins may be exploited for water and fat absorption, thickening, and for stabilizing of emulsions and foams.

Proteins provide the basis for the texture and structure of many food products as a fibrous constituent per say or in the soluble form which form a chewable fibrous product by a series of texturization processes.

Structure Formation Properties (protein-protein interactions)

As mentioned above, the formation of a gel involves protein-protein interactions besides the role of water. It involves interplay of attractive and repulsive interactions between different polypeptide chains. The gelation plays a role in water absorption, water control and thickening etc. Another crucial property of the proteins is **dough** formation. You know that the dough is nothing but a strongly cohesive and viscoelastic mass formed from gluten, the proteins present in wheat grain endosperm. This also has contributions from the starch granules, some lipid and other soluble proteins. The dough is stabilized by hydrogen bonding between different amino acid side chains, hydrophobic interactions between apolar amino acids and numerous disulphide (-S-S-) cross linkages. In other words we can say that dough formation is a consequence of **protein-protein interactions**.

Surface Properties (protein-interface interactions)

Proteins are surface active agents. You are aware that in the three dimensional structure of the proteins in aqueous solutions, the hydrophobic amino acids are buried inside in the bulk, while the amino acids with hydrophilic side chains are on the surface. The active surface of the proteins can interact with a wide variety of molecules like water, lipids, volatile flavours, carbohydrates and even other protein molecules. Due to this, the proteins find extensive applications as emulsifiers in deserts, whipped creams and spreads etc. The proteins also stabilize emulsions and contribute to the physical and rheological properties like viscosity, thickness and elasticity etc. Proteins are good at producing foams in cakes ice creams etc. where these exist with varied textures.

The surface properties of the proteins may be exploited in binding the desirable flavours on to it, though sometimes it may be disadvantageous as these can also bind undesirable flavours causing to initiate de-odourisation. In addition, the active surface of the proteins may provide site for the binding of a number of other substances like pigments, synthetic dyes and substances with mutagenic activity. These binding interactions may lead to adverse nutritional or toxic consequences.

Viscoelastic: having flow-resistant as well as stretchy properties

Rheology: study to deformation and flow of matter

7.5.3 Food Applications of Protein Concentrates, Isolates and Hydrolysates

The protein concentrates and isolates are the products obtained by selectively removing the non-protein ingredients from a protein source so as to obtain a product that is rich in its protein content. The procedure is such that the nutritional and functional properties of the proteins are retained. These find extensive applications in different formulations so as to impart nutritional as well as functional properties to them. The protein hydrolysates, on the other hand are the products obtained on treating the proteins with enzymes that hydrolyze them. These products consist of mixtures of amino acids and small products. These hydrolysates have superior nutritional qualities and higher bioavailability.

The **Soy Protein Concentrates (SPC)** are prepared from high quality, sound, clean, dehulled soybean seeds by removing most of the oil and water soluble non-protein constituents. It contains not less than 70% protein on moisture free basis. The most important application of SPC is in food industry primarily in comminuted meat, poultry and fish products like patties, sausages and fish sticks etc. The SPC increase the water and fat retention in these products. Besides these, the SPC are also used as stabilized dispersions in milk, beverages and simulated dairy products like sour cream analogues.

The **Soy protein isolates (ISP)** are the major proteinaceous fraction obtained from dehulled soybeans and contain at least 90% protein on moisture free basis. The major food applications of ISP's are in meat products as a meat replacer, in sea foods like fish sausages and in cereal, bakery and dairy products.

The **Whey Protein Concentrate (WPC)** is a highly nutritious product obtained by selectively removing water, minerals and lactose from whey. These are removed by physical separation techniques like precipitation, filtration or dialysis. The WPCs find extensive applications in baked goods and contributes towards the product browning, crust and flavour development. The concentrates with high viscosity are used in ice creams, processed cheese and fresh dairy applications.

The **protein hydrolysates** are obtained by hydrolysis of food proteins by using proteases like chymotrypsin, papain, thermolysin and trypsin. The hydrolysis process alters the composition and functional properties of the proteins like gelation, foaming and emulsification. The hydrolysates are used in soups and sauces and are important for the people who cannot digest solid foods.

After having an understanding of the structure and properties of proteins it will be easy for you to understand the behaviour of enzymes and their role in food industry. Let us read about enzymes in the section that will follow exercise.

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.

Complete the statements given below with appropriate answers.

- i) The net charge of proteins at this pH is zero.....
- ii) It is due to the presence of amino acids with hydrophilic

- side chains that proteins possess this food application
- iii) Food processes like gelation, emulsification and foaming relate to this property of proteins

7.6 ENZYMES

Enzymes are the proteins that catalyze biochemical reactions. Study of the important biochemical reactions was started many years ago, from the time of Louis Pasteur, who for the first time demonstrated the fermentation of glucose by yeast. The catalytic agent of yeast cell was subsequently identified and named as **ferment**. An enzyme can be a large protein made up of several hundred amino acids, or several polypeptides that act together as a unit. Enzymes have molecular weights ranging from 10,000 to 2,000,000.

Enzymes may sometimes have a non-protein component attached to the protein part. This may be an organic compound or a metal ion. While the former is called as **coenzyme**, the later is best known as **cofactor**. The protein part and non-protein part together form the **holoenzyme**, as illustrated in Fig. 7.6. Sometimes, the non-protein part remains so tightly bound to the protein part that it cannot be dissociated. Such non-protein part is called as a **prosthetic group**. When the non-protein component dissociates from the protein part, the enzyme loses its catalytic function and is called an apoenzyme as can be seen in the Fig. 7.7.

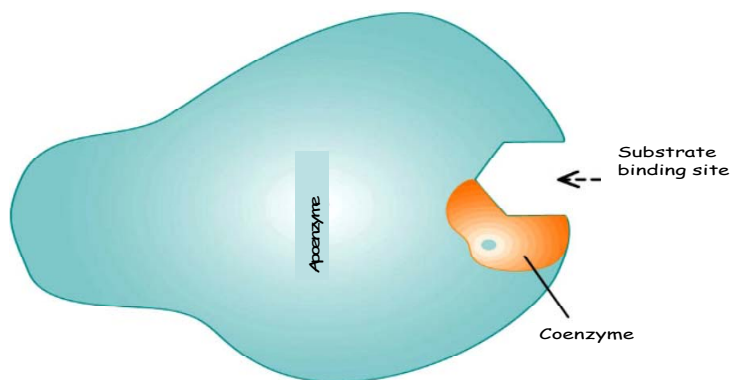


Fig.7.7: Schematic representation of enzyme with protein and non-protein part

7.5.1 Nomenclature and Classification of Enzymes

Conventionally, the trivial or common names of the enzymes were derived either from the names of the substrate they acted on, or on the reaction they catalyzed or both. These ended in a suffix ‘-ase’ for example, *urease* is an enzyme acting on urea. However as the number of enzymes known went up, a need to have a formal scheme of nomenclature was felt and accordingly, there is an enzyme nomenclature system in place. According to this system, the enzymes are grouped into six classes; each class is subdivided into several subclasses, which are further subdivided. Every enzyme is characterized by a code number.

The code numbers of the enzymes are prefixed by **EC (Enzyme Commission)** and contain four numbers separated by points, with the following meaning:

- (a) the first number shows to which of the six main classes an enzyme belongs
- (b) the second figure indicates the subclass
- (c) the third figure gives the sub-subclass, and
- (d) the fourth figure is the serial number of the enzyme in its subclass.

For example, the EC number of the enzyme catalase is EC 1.11.1.6

The major classes and the type of reaction catalyzed by them are given below:

Oxidoreductases: The enzymes of this class (EC 1) catalyze oxidation-reduction reactions. Common names include *dehydrogenases*, *oxidases*, *reductases* and *catalases*.

Transferases: These are the enzymes (EC 2) which catalyze the transfer of a group, e.g., a methyl or glycosyl group, from one compound to another. In many cases, the donor is a cofactor (coenzyme) carrying the group to be transferred. Common enzymes of this group include *acetyltransferase*, *methylase*, *protein kinase* and *polymerase*.

Hydrolases: These enzymes (EC 3) catalyze the hydrolytic cleavage of C–O, C–N, C–C and some other bonds, including phosphoric anhydride bonds. Their trivial names are formed by adding the suffix ‘ase’ to the substrate which they hydrolyze. Examples include *protease*, *nuclease*, *phosphatase*.

Lyases: These enzymes (EC 4) cleave C–C, C–O, C–N and other bonds by elimination, forming double bonds or conversely adding groups to double bonds. Common examples include *decarboxylase*, *aldolase*, *dehydratase* (if water is eliminated) or hydro-lyase (if the reverse reaction is more important or the only one which can be demonstrated).

Isomerases: These enzymes (EC 5) catalyze geometric or structural changes within a molecule. According to the type of isomerism, they may be called *racemases*, *epimerases*, *cis-trans isomerases* (5.2), *isomerases*, *tautomerase*s, *mutases* or *csycloisomerases*.

Ligases: These are also called synthetases (EC 6) and catalyze the linkage of two molecules coupled with the hydrolytic breakdown of a pyrophosphate bond in ATP or an analogous compound. The bonds formed are often high energy bonds. The second figure in the code number indicates the bond formed, e.g. C–O (6.1), C–S (6.2) etc. Examples include *peptide synthase*, *aminoacyl-tRNA synthetase*, *DNA ligase* and *RNA ligase*.

Monomeric and Oligomeric Enzymes

On the basis of polypeptide units constituting the enzyme, these are categorized into **monomeric** and **oligomeric** enzymes. As is evident from the name itself, the monomeric enzymes contain a single polypeptide unit, while the oligomeric enzymes contain two or more such units. The monomeric enzymes are primarily *proteases* i.e., they catalyze the hydrolysis of peptide bonds of other protein molecules. The examples being *serine protease*, *thiol protease* etc.. The oligomeric enzymes on the other hand, include a vast majority of enzymes. The examples being, *lactose synthase*, *lactate dehydrogenase* and *pyruvate dehydrogenase* etc.



Check Your Progress Exercise 5

Note: a) Compare your answers with those given at the end of the unit.

1) Fill in the blank spaces in the following.

- a) The tightly bound non-protein part of enzymes is called the
- b) The enzymes responsible for cleavage of bonds and formation of double bond belong to the class
- c) is an example of an enzyme catalyzing hydrolytic cleavage in biochemical reactions.
- d) are also called due to their involvement in linking two molecules and forming bonds.

7.7 ENZYME UTILIZATION IN FOOD INDUSTRY

The biocatalytic activity of the enzymes is of immense importance in food technology. Many reactions catalyzed by enzymes contribute towards the desired attributes of the processed food. At the same time, a number of enzymatic reactions produce undesirable results. Further, the enzymes may be used in industry as components of living cells or after isolation in free or immobilized forms. Let us take up some of the applications of enzymes in the food industry.

Blanching: A hot-water or steam treatment of raw foodstuffs to inactivate enzymes which otherwise might cause quality deterioration, particularly of flavour, during processing or storage.

Ale: A fermented alcoholic beverage containing malt, similar to beer, but heavier.

Stout: A strong, very dark beer.

Whey: The watery part of milk, separated from the curds, as in the process of making cheese.

Bread making: In baking bread, the preliminary process involves the mixing of wheat flour (mainly starch and proteins) with yeast and water. Starch gives glucose, maltose and some oligosaccharides. Glucose and maltose are then metabolised by the enzymes in yeast, and carbon dioxide is formed. This CO₂ then disintends the protein framework of the dough, ready for baking.

Vegetable preservation: You know that the fresh vegetables contain a number of enzymes. In the process of preservation of these vegetables, the enzymes must be inactivated; else the vegetables would soon get deteriorated. This inactivation is achieved by a process called **blanching**, blanching helps in inactivating the enzymes in vegetables. Therefore it is essential blanch the vegetables before their preservation.

Brewing industry: Brewing refers to the manufacture of beer and other malt beverages like ale and stout. The process involves germination of barley under moist conditions which is then dried and the malt so obtained is the main starting material. The reserve starch is broken down by the amylase present to give, among other products, glucose, maltose and soluble starch. The grains are then roasted and the soluble component called **wort** is extracted with water. This wort is then fermented in presence of yeast to obtain alcohol. The alcohol thus accrued is separated by distillation for making different types of alcoholic drinks.

Cheese production: involves the conversion of the milk protein, k-casein to paracasein by a defined, limited hydrolysis, catalyzed by chymosin (rennin). Rennin the gastric enzyme of the calf is used in the form of a crude extract, powder or paste. In the presence of Ca²⁺, paracasein clots and may be separated from the whey after which the clot is allowed to mature under controlled conditions to form cheese.

Tenderizing of meat: when meat is cooked fresh it is quite tender. However, with the passage of time the muscle becomes inextensible and is tough when cooked. The meat can be tenderized with the help of **proteolytic** enzymes e.g. proteases. For this purpose, the meat is kept at low temperature ($\sim 4^{\circ}\text{C}$) for many weeks whereby the enzymes present in the meat tenderize it. This process can be hastened by dusting proteolytic enzymes over the meat before frying or boiling it.

Proteolytic enzymes: catalyzing the hydrolysis of peptide bonds

Enzymes find a number of application in food industry by way of immobilized enzymes about which you will study in the next subsection after answering the following SAQ.

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) Choose the correct answer for the following.

Proteolytic enzymes are able to tenderize meat because

- i) these enzymes work at low temperatures.
- ii) these enzymes do not take very long for catalyzing the reaction.
- iii) the enzymes can catalyze the hydrolysis of peptide bonds.
- iv) the meat gets softened after keeping it as such for sometime.

7.7.1 Immobilized Enzymes

The enzymes used to catalyze a given reaction in food processing normally get inactivated in the process and cannot be reused. It was attempted to separate them from the product and put to use again. It could be achieved by attaching the enzyme to a water-insoluble solid support, called the **matrix**. This is called **enzyme immobilization**.

You must have observed that if you keep a cut apple exposed to air for some time it starts turning brown. A wrong notion associated with this type of browning is that the change is due to the presence of iron in that particular fruit or vegetable. This is actually incorrect and has different reasons. In recent past the immobilized enzymes have become an indispensable tool in food processing. The immobilization of the enzyme can be achieved by chemical or physical methods. In chemical methods, the enzymes are bound to a solid support through covalent bonding. In case of physical methods, the enzymes are either adsorbed on the solid support, entrapped in gels or are encapsulated behind semi-permeable membranes. The enzymes cannot be recovered from the immobilized enzymes, prepared by chemical means whereas the physical immobilization of the enzymes is reversible.

There are several of advantages of immobilized enzymes. Some of these are given below:

- Easy recovery of the enzyme after the process: The immobilized enzymes are added to the reaction mixture and removed by filtration after the reaction is over. This leads to cost efficiency.
- The greater efficiency and control of their catalytic activity,
- Reusability of the enzyme,

Immobilised enzymes have been defined as enzymes that are physically confined or localised, with retention of their catalytic activity, and which can be used repeatedly and continuously

- Improved thermal stability of the enzyme allowing higher processing temperatures.

Treatment of corn syrup with glucose *isomerase* gives high fructose syrup that is 50 per cent more sweet. This is a result of conversion of glucose to fructose by the enzyme. The high fructose syrup finds application in the manufacture of aerated drinks. Nowadays the immobilized *glucose isomerase* is used on a commercial scale for the conversion of glucose to fructose.

7.7.2 Enzymatic Browning

You must have observed that when you keep the cut apple exposed to air for sometimes, it starts turning brown. A wrong notion associated with this type of browning is that it is due to the presence of iron in that particular fruit of vegetable. This is actually incorrect. It has different reasons. You will read and understand it in the following paragraphs.

The browning of some cut fruits and vegetables is called **enzymatic browning** and is due to the activity of a group of enzymes called *phenolases*. The enzymatic browning is a result of two reactions. One being the conversion of *o*-dihydroxyphenols to *o*-quinones and the other is hydroxylation of some monohydroxyphenols to dihydroxyphenols. The browning of certain fruits on cutting is due to the polymerization of *Rothe* quinines which are formed in the enzymatic reaction.

All the fruits do not brown on cutting. This may be due to the absence of the browning enzymes or that of the suitable substrates. You would agree that the browning is not a desirable phenomenon therefore we need some kind of intervention to retard or prevent it. Applying lemon juice on cut banana or dipping the cut fruits in ascorbic acid or in dilute salt solution are some such interventions. These help by blocking the contact with air or by reducing the enzymatic activity.



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) Tick mark (✓) in front of the right statement(s) and mark (X) in front of wrong statement(s) given below.
 - i) Enzyme catalysis is an expensive technique because of inability to recover the enzyme used in a process.
 - ii) Immobilisation of enzyme is one technique to make the use of enzymes cost effective.
 - iii) The recovery of enzymes after enzyme immobilisation is very difficult
 - iv) All the types of fruits and vegetables show enzymatic browning



7.8 LET US SUM UP

Proteins are polymeric biomolecules present as important components of plant and animal cells. The main plant sources of proteins include cereals, pulses and oilseeds. The animal sources include meat, poultry and fishes. Proteins are also obtained from microbial sources. The proteins obtained from microbial sources are called single cell proteins.

Proteins are classified on the basis of their shape and size, product of hydrolysis, and biological functions. These are made up of amino acids that consist of an amino and a carboxylic group. The properties of proteins, therefore, reflect the reactions related to both the groups. The amino acids combine together through peptide bonds to form peptides. The peptides may be di, tri, tetra, and so on depending upon the number of amino acids combining. When the number of amino acids is very large, polypeptides are formed. Polypeptides with more than 50 amino acids form protein.

The structural organization of proteins has four levels via, primary, secondary, tertiary and quaternary. The primary structure is the chain of amino acids while other structures are a result of folding of the chain to give rise to various shapes and sizes of proteins.

Proteins find a number of food applications. These are used in emulsification gelation, foaming etc during food processing and preparation. Proteins have an important role in the form of enzymes acting as catalysts in the biochemical reactions. Enzymes initially were named after the substrate or the reaction catalyzed by these. Later these were systematically named and classified according to the Enzyme Commission rules. Enzymes find a number of food applications e.g. bread making, vegetable preservation, brewing etc. They find application in the form of immobilized enzymes also.

7.9 KEY WORDS

Albumins : A class of simple, water-soluble proteins that can be coagulated by heat and are found in egg white, blood serum, milk, and many other animal and plant tissues.

Blanching : A partial precooking by plunging the food into hot water (82-95°C) for ½-5 min. Fruits and vegetables are blanched before canning, drying, or freezing, to soften the texture, remove air, denature enzymes that may cause spoilage when frozen, and remove undesirable flavours.

Enzymatic Browning : Enzymatic browning is a chemical process involving polyphenol oxidase or other enzymes that create melanin's, resulting in a brown color. Enzymatic browning is an important color reaction in fruit, vegetables, and seafood. Enzymatic browning of fruits and vegetables creates heavy economic losses for growers.

Essential Amino Acids : An amino acid that must be obtained from the diet so that the body can synthesize vital proteins. The nine essential amino acids are isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine, and histidine.

Immobilized Enzyme : An enzyme which is attached to an inert, insoluble material such as sodium alginate. This

can provide increased resistance to changes in conditions such as pH or temperature. The techniques for immobilization include simple absorption, ionic to covalent binding.

Isoelectric Point : The pH value of the dispersion medium of a colloidal suspension at which the colloidal particles do not move in an electric field.

Tenderization : To make (meat) tender, as by marinating, pounding, or applying a tenderizer. Natural tenderizing is caused by the action of enzymes already in tissues. This effect can be enhanced by quick freezing before rigor mortis sets in, and by hanging the meat at the proper temperature for the proper time, especially just before cooking, also called conditioning.

7.10 TERMINAL QUESTIONS

- 1) Which amino acid will be at the C terminal and which will be at N terminal in tripeptide valylisoleucylalanine?
- 2) What is meant by single cell proteins? What are their advantages?
- 3) Define and distinguish simple, conjugated and derived proteins.
- 4) What are the four organizational structures of proteins. What is the difference amongst all of these?
- 5) What do you understand by the functional properties of proteins? How are these depicted in the foods?
- 6) Define the terms enzymes, coenzymes, cofactors and prosthetic groups.
- 7) Define immobilized enzymes and give an example of its application in food industry.

7.11 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress Exercise 1

- 1) spinach > carrot > fresh beans > milk > lentils > soybean

Check Your Progress Exercise 2

- 1) i) globular, fibrous
ii) structural
iii) transport
iv) derived

Check Your Progress Exercise 3

- 1) ii)
- 2) i) – ii), ii) – iii),
iii) – i)

Check Your Progress Exercise 4

- 1) i) Isoelectric point
ii) Emulsifying property
iii) Solubility and Precipitation

Check Your Progress Exercise 5

- 1) a) prosthetic group

- b) lyases
- c) Protease / nuclease / phosphatase
- d) Ligases, synthetases

Check Your Progress Exercise 6

- 1) iii)

Check Your Progress Exercise 7

- 1) i) ✓ ii) ✓ iii) x iv) x

7.12 ANSWERS TO TERMINAL QUESTIONS

- 1) Valine will be at the N terminal and alanine at C terminal.
- 2) Single cell proteins are those obtained from microbial sources. These have advantages of good yield and cost effectiveness.
- 3) Simple proteins are formed only by amino acids, conjugated have some non-protein part and the derived are the one obtained as hydrolytic products of any of the former two.
- 4) The four organizational structures are primary, secondary, tertiary and quaternary. The primary level of organization has a sequence of amino acids, secondary shows folding of these chains, tertiary depicts the three dimensional folding while quaternary has two or more polypeptide chains folded to give these dimensional structures.
- 5) Functional properties of proteins are related to their functions in biosystems. In foods proteins functions as gelating, emulsifying and foaming agents which is due to their water binding, hydrolytic and other properties.
- 6) **Enzymes** are protein molecules functioning as catalysts in biochemical reaction
Coenzyme is the non-protein part of enzymes which could be an organic molecules or a metal.
Cofactor is the metal as non-protein part of an enzyme.
Prosthetic group is the non-protein part of enzyme tightly bound to it.
- 7) Immobilized enzymes are the enzymes which are separated after catalyzing a biochemical reaction for reuse. The enzyme is absorbed on a solid support called the matrix. An example of immobilized enzyme is *glucose isomerase* which is responsible for high fructose syrup during treatment of corn syrup.

7.13 SOME USEFUL BOOKS

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

John deMan (1980). *Principles of Food Chemistry*, The AVI publishing Company Inc.

Swaminathan M. (1999). *Essentials of Food and Nutrition*, vol. I The Bangalore printing and publishing Co. Ltd., Bangalore

Bennion Marion (1980). *The Science of Food*, John Wiley and sons

Manay N. Shakuntala and M. Shadaksharaswamy (1987). *Foods: Facts and Principles*, Wiley Eastern Ltd.

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Starch Gelatinization

Starch gelatinization is a phenomenon in which the starch granules primarily absorb water, swell and eventually burst out to form a gel in the presence of water and heat. Gelatinization of starch is a method that requires **starch** (any sources like cornstarch, rice flour etc.) as a solute and **water** as a solvent.

Here, water serves as a **plasticizer** that smoothens the resulted paste. Starch is a **complex polysaccharide** that solubilizes or gelatinizes in warm water by forming a thick paste. Thus, it exhibits a unique property of gelatinization, and the factors like water content, temperature, pH, sugar etc., may influence the gelatinization process.

Starch gelatinization is a process of **thickening** used to prepare sauces, soups, puddings, custard etc. This post describes the definition, process and factors affecting starch gelatinization. You will also get to learn the meaning, structure and solubility of the starch.

Content: Starch Gelatinization

1. [Definition](#)
2. [What is Starch?](#)
3. [Starch Gelatinization Process](#)
4. [Factors Affecting](#)
5. [Conclusion](#)

Definition of Starch Gelatinization

It is a process in which the solid starch granules turn into a gelled starch when dissolved in water, followed by heating the suspension. Starch granules primarily **swell** as the intermolecular bonding between the starch molecules breaks under high heat (50 degrees Celsius or above), resulting in more **water absorption**. Eventually, the starch granules **burst**, and they start leaching the crystalline layers as **gelatinous sheets** into the surrounding water.

What is Starch?

It is a **polymeric carbohydrate** or polysaccharide produced mostly by green plants, and it makes a significant source of diet for animals and humans. Thousands of monomeric glucose units contribute to the structure of starch. The **glycosidic bond** joins each glucose unit. The structure of starch includes two major components, namely amylose and amylopectin.

1. **Amylose** contains linear and helical chains of alpha-D-glucose monomers. It is poorly soluble in water and slowly digestible.
2. Conversely, **amylopectin** contains branched chains of alpha-D-glucose monomers. It is more soluble in water and more susceptible to enzyme digestion.

Unique Properties

- Starch hydrolysis yields constituent sugars.

- It remains insoluble in water.
- Starch undergoes gelatinization when heated in water.
- Gelated starch undergoes retrogradation upon cooling.
- It gives blue colour with iodine solution.

Starch Sources

Starch is produced naturally by plants, and some of the major starch sources are given hereunder.

- **Cereals:** Barley, corn, oats, rice, semolina, wheat, millets etc.
- **Legumes:** Beans, chickpeas, soybeans etc.
- **Vegetables:** Cassava, potatoes, taro, arrowroot, sweet potato etc.

Starch Solubility

Starch is a water-insoluble compound, thereby absorbing less water. The addition of starch into the cold or normal water form a suspension. Once the water is subjected to a temperature of 50 °C or above, the starch absorbs more water and gradually swells. By subjecting water and starch to heat, starch solubilizes and forms a thickened paste.

Process of Starch Gelatinization

It involves the following stages:

Granule Swelling

Starch granules swell when heated in water at 50 degrees Celsius or above due to the entry of water molecules into the **amorphous space**. On heating, the starch granules **absorb water** and swell irreversibly.

Double-helical Melting

Then water enters the double-helical structures of the amylopectin or the **crystalline structure** of starch. However, the water cannot enter these crystalline regions at ambient temperature. By providing continuous heating, the temperature increases and the starch granules absorb more and more water, start bumping into each other and eventually **rupture**.

The water molecules break the intermolecular bonds, and the crystalline regions **diffuse**, resulting in the dissolution of the amylose chains. Thus, it results in the distortion of crystalline regions.

Amylose Leaching

Ultimately, the **amylose chains** separate into an amorphous form and leach into the surrounding water. The mixture attains the maximum viscosity as the amylose leached into the surrounding liquid causes the mixture to **thicken**. Complete gelatinization occurs nearly at a temperature of 96 degrees Celsius.

Ageing or Retrogradation

As the above mixture is cooled, it thickens even more and becomes a gel at about 38°C. Thus, the gelled starch gradually thickens when chilled for an extended period (hours or days).

In other words, retrogradation is the **recrystallization** of starch in which the amylose and amylopectin chains realign again into a **more crystalline structure**.

In retrogradation, the water molecules trapped between the starch granules leak out, allowing the amylose/amylopectin chains to recrystallize. Amylose-amylose, amylose-amylopectin, and amylopectin-amylopectin are the three molecular associations that could form during the retrogradation.

Retrogradation is more likely to occur in a **high amylose starch**. The gelatinized starch may deteriorate during its storage time due to incomplete gelatinization. As a result, ungelatinized starch molecules are more susceptible to bacterial erosion than gelatinized starch granules.

Gelatinization Temperature: Here, we need to understand one important term, which is gelatinization temperature. So, it can be defined as the temperature at which the starch granules rapidly swell, lose birefringence and yield a thickened paste.

Gelatinization temperature depends upon the type of starch, the ratio of amylose and amylopectin and the water content. It varies in different starch sources, and some of the examples are mentioned hereunder.

Sources of Starch

Gelatinization Temperature

Barley	51-60 °C
Wheat	58-64 °C
Potato	60-65 °C
Corn	62-72 °C
Rice	68-78 °C

Factors Affecting

1. **Water:** Starch gelatinization requires sufficient water so that the granules can absorb water and swell. The amount of water varies depending upon the amylose and amylopectin content within the starch.
2. **Temperature:** Generally, starch gelatinizes on heating. Large starch granules gelatinize at a relatively lower temperature like in potatoes. Oppositely, small starch granules gelatinize at a high temperature like in rice.
3. **pH:** A pH below 4 decreases the viscosity of the gelled starch.
4. **Time:** Heating mixture beyond the gelatinization temperature results in the loss of viscosity.

5. **Stirring:** Initially, constant stirring is necessary to ensure uniform consistency and to prevent lump formation. But, too much agitation of the mixture may lead to premature rupturing of the starch granules.
6. **Sugar:** It competes with starch for the availability of water, thereby decreasing the onset of gelatinization. Sometimes, it may inhibit complete gelatinization.
7. **Fat and Protein:** They form a layer around starch granules, restricting them from absorbing water and delaying gelatinization.

Conclusion

Gelatinization is the **irreversible** process with respect to the shape of starch molecules. Oppositely,

Retrogradation is the **reversible** process in which the solubilized starch chains realign, forming hydrogen bonds by expelling water to form a more crystalline structure

Retrogradation of Starch

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Retrogradation of starch is just opposite of the [starch gelatinization](#). Here, the term retrogradation denotes the reversal mechanism. The gelation of starch contains disaggregated starch molecules. But, the disaggregated **amylose** and **amylopectin chains** realign during retrogradation of a starch gel. We could see the retrograde starch after a long-term cooling or storage of the starch gel. Boussingault introduced this process in 1852. **Freezing** is a factor aggravating the retrogradation process. Upon cooling, the amylose and amylopectin chains retrograde in a parallel fashion. Later on, the hydrogen bonds reform between the chains.

Then, it leads to the formation of a compact or **crystalline structure** of starch. But, the crystallinity of retrograded starch is not the same as the native starch granule.

This post describes the meaning, key points, examples and factors affecting starch retrogradation. We will also discuss how does starch retrogradation occur?

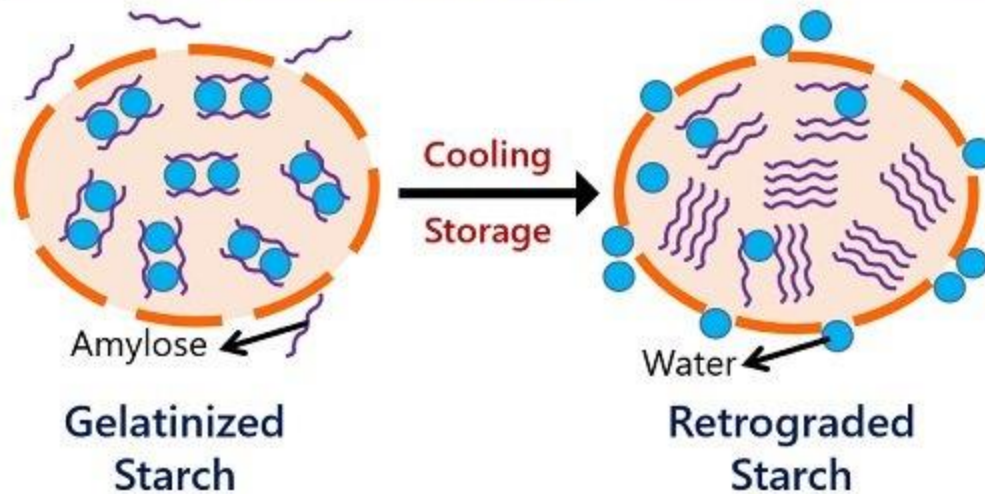
Content: Retrogradation of Starch

1. [Meaning](#)
2. [How Does Retrogradation Occurs?](#)
3. [Key Points](#)
4. [Examples](#)
5. [Factors Affecting](#)
6. [How to Prevent Retrogradation?](#)

Meaning of Starch Retrogradation

Starch retrogradation refers to the **recrystallization of starch** upon cooling the starch gel. The process is thermoreversible. It involves the **realignment** of amylose chains. Also, it involves the **aggregation** of amylopectin chains into a more crystalline form.

Starch Retrogradation



Or, we can say it is like a **syneresis** of starch gel. Syneresis is the discharge of a liquid or water from a gel. Likewise, water expels out of the starch granules during starch retrogradation.

How Does Retrogradation Occurs?

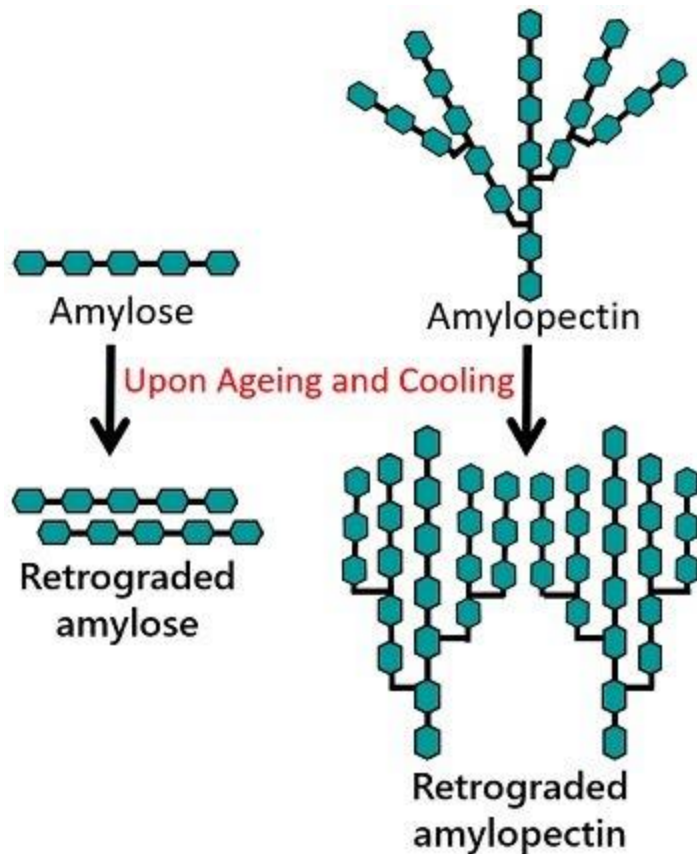
Retrogradation is an ageing process of viscous or gelatinized starch. Upon **ageing** of the **gelatinized substance**, amylose and amylopectin reassociate or recrystallize. Starch retrogradation has the following two stages:

1. *Short-term retrogradation*

It includes linear amylose chains. Amylose recombines in an irreversible manner to produce a crystal nucleus. It is a rapid process, as the reassociation becomes faster due to the linear structure of amylose. Emulsifiers may reduce the initial firmness or **amylose retrogradation**.

2. *Long-term retrogradation*

It includes branched and more complex amylopectin chains. Unlike amylose, amylopectin retrogradation takes a long time to crystallize. It takes several days or weeks. This is because of the branched structure of the amylopectin. The introduction of enzymes reduces the long-term firmness or **amylopectin retrogradation**.



Thus, the retrogradation rate differs in amylose and amylopectin polysaccharides. Amylose retrogradation is a faster event than amylopectin retrogradation.

Note: Amylose has high crystallinity and is susceptible to retrogradation. In contrast, amylopectin crystallizes only outside the globule and shows slow retrogradation.

Key Points

1. Starch is a **homopolysaccharide**. It comprises two α -d-glucan chains, amylose and amylopectin. The starch structure and composition vary, depending on the type of plant species.
 - **Amylose** exists as a linear chain. It contains about 500-2000 glucose units.
 - In contrast, **amylopectin** has a branched structure. It contains about 1,000,000 glucose units.
2. Starch retrogradation is the starch's **physicochemical property**. It is the stage after starch gelatinization. By cooling or ageing the starch gel for a longer period, retrogradation of starch units occur. During retrogradation:
 - The glucose units of amylose combine to produce a **double-helix**.
 - The glucose units of amylopectin **recrystallize** through a combination of its small chains.
3. The above interaction results in a more **ordered** or **crystalline form**. Hydrogen-bond reforms within such units and holds up these units together. Also, it accounts for the crystalline structure of the retrograded starch.
4. Starch retrogradation involves a series of **physical changes** like:

- Increased viscosity
 - Turbidity of pastes
 - Gel formation
 - Exudation of water (syneresis)
5. The free starch molecules form a **network** by forming ordered structures. These reorganized structures differ from the crystalline structure of the native starch granules.
 6. Retrograded starch is **less digestible**. This is because digestive enzymes have difficulty in breaking the starch crystals.

Retrogradation of Starch Examples

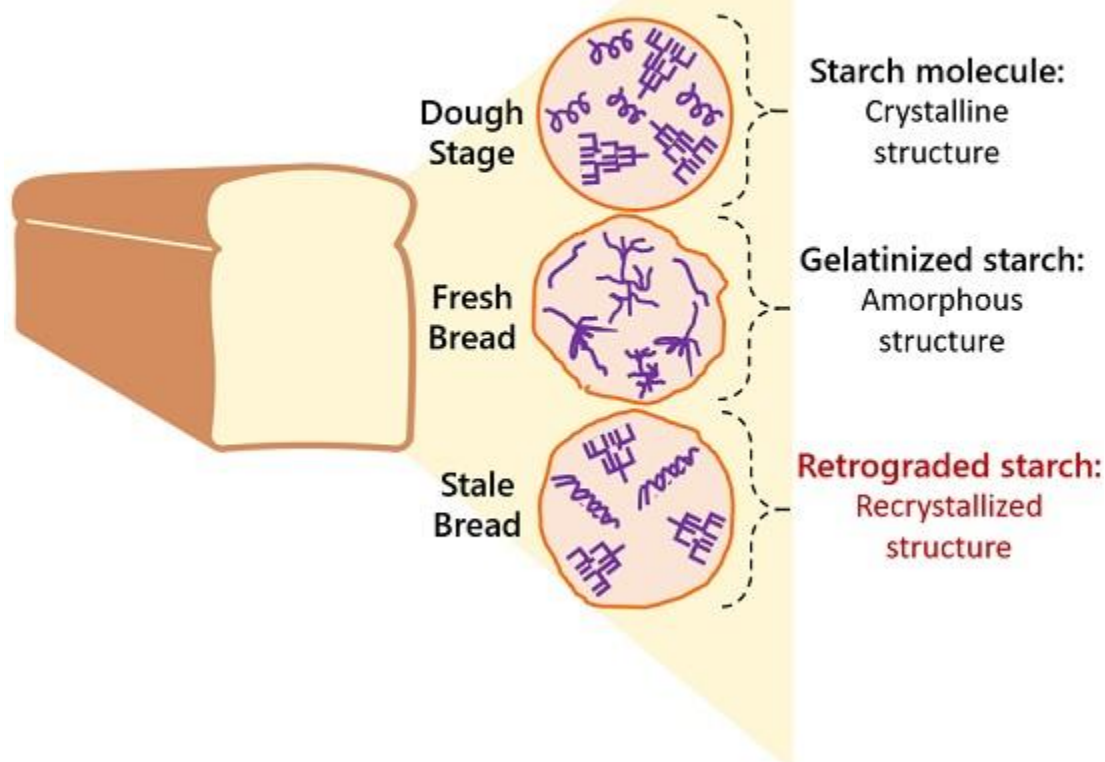
Here, we will take the example of starch retrogradation in bread and rice. Also, we will study the changes in starch granules till the retrogradation process:

Bread Retrogradation

In the **dough stage**, starch molecules are in crystalline form. Here, the linear and branched chains of amylose and amylopectin appears

Then, the raw bread dough **gelatinizes** at about 150° C. The starch absorbs water, swells, and becomes semi-firm during this stage. After baking, the loaf is taken out of the oven.

Starch Retrogradation In Bread

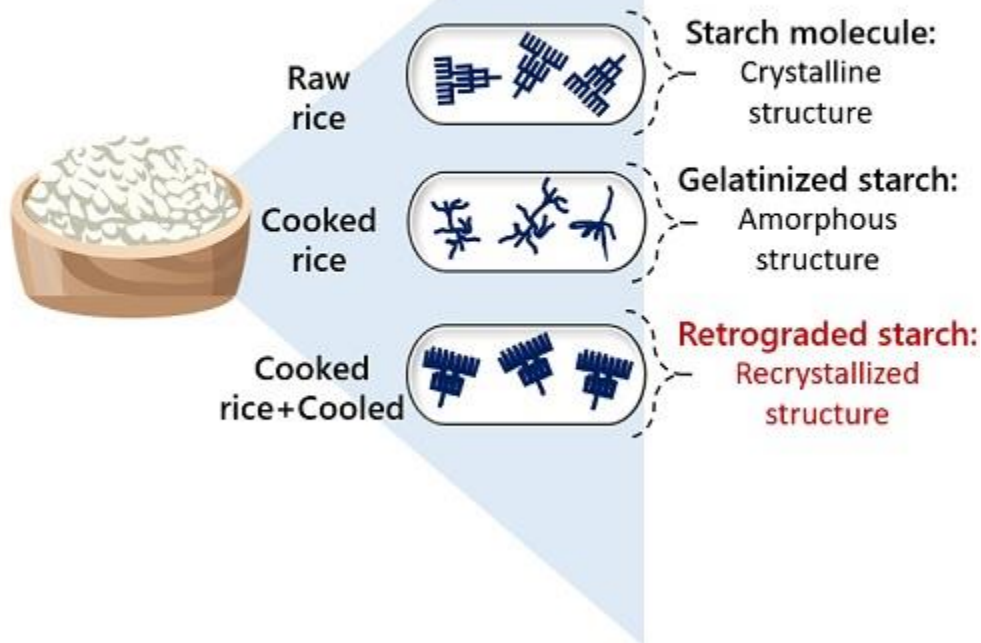


Upon **ageing** and **cooling** below the gelatinization temperature, the starch molecules recrystallize. The starch expels water, contract, and becomes harder during this stage.

Rice retrogradation

Starch molecules in **raw rice** have a crystalline structure. By **cooking rice** in water, the starch molecules gelatinize. The rice grain swells by absorbing water. Starch molecules rearrange into a crystalline structure once you **refrigerate** or **age** the cooked rice.

Starch Retrogradation In Rice Grain



Factors Affecting

Factors affecting retrogradation involve:

- 1. Type of starch:** The retrogradation rate differs depending upon the starch type and composition. Starch with high amylose concentration retrogrades faster due to linear chain structure.
- 2. Length of the amylopectin chains:** Amylopectin with short branches constitute the crystalline region. More amylopectin concentration in starch granules results in **greater crystallinity**.
- 3. Proteins:** These serve as emulsifiers. They have a negative effect on the retrogradation properties of the paste. Protein-starch complexes **retard** retrogradation during storage.
- 4. Lipids:** Monoglycerides are lipids that interact with free amylose. Free amylose forms a complex at a concentration of monoglycerides >1%. Also, amylopectin-lipid complex forms. This interaction obstructs the amylopectin crystal formation. And, resulting in a **decrease** in retrogradation.
- 5. Physical modification:** Repeated freezing of the starch gel **aggravates** retrogradation. Thus, the resulting starch formed is RS-III (resistant starch). RS-III is resistant to amylase digestion.

6. Chemical modification: A chemical process like **acetylation** reduces the retrogradation tendency of starch. Reagents like anhydrous acetic acid or vinyl acetate cause esterification of native starch. The process requires an alkaline catalyst (NaOH, KOH, Ca (OH)₂, or Na₂CO₃).

How to Prevent Retrogradation?

Some measures can prevent retrogradation.

- Chemical starch modifications like hydrolysis and esterification produce starches resistant to retrogradation.
- Adding fat and protein as an emulsifier can also reduce retrogradation.
- Sodium chloride and sodium nitrate are also some reagents preventing starch retrogradation.
- Sugar molecules also delay retrogradation. They interact with starch chains to stabilize the amorphous regions of the granule.

By preventing retrogradation, we can increase the **longevity** of food items.

As well as changing the colour of the food, dextrinization can also change the taste, aroma, or even the flavour. A typical example is toast.

How does it happen?

You may have noticed if you cook baked food in the oven, such as a cake, or bread, the outside of the food goes a darker colour. During the heating process, the starches within the food are broken down (by a chemical reaction) into sugars called dextrin. Dextrins are brown in colour and have a distinct taste and consistency. Producing dextrin therefore results in a change in colour of food to golden brown. This is the process called dextrinization.

Over heating

What happens if the food is cooked for too long? If toast is overcooked it goes black and burnt. Overcooking causes the starch to turn to carbon.

Recap: some of the dextrins produced are pyrodextrins. Pyrodextrins can give the bread crusts and toast a “toasted” flavour.

the process of heating sugar (such as granulated white sugar or the sugar contained in a food) at high temperature so that water is removed and the sugar is broken down (as into glucose and fructose) and then reformed into complex polymers producing vfcg a sweet, nutty, or buttery flavor

and golden-brown to dark brown color : the nonenzymatic process of changing sugar or the sugar content of a food into caramel (see [CARAMEL sense 1](#))