EXTERNAL STUDIES PROGRAMME

ABN 200

Introduction to Agricultural Biochemistry

**University
of
Ibadan,
Ibadan.**

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ABN 200

Introduction to Agricultural Biochemistry

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IBADAN EXTERNAL STUDIES PROGRAMME SERIES

ABN 200

INTRODUCTION TO AGRICULTURAL BIOCHEMISTRY

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LECTURE ONE

General Introduction

Introduction

The Agricultural Biochemistry and Nutrition (ABN 200) titled introduction to Agricultural Biochemistry is an introductory to fundamental nutrients in food. Nutrients are group of food constituents of the same general chemical composition that aids in the support of life. These unavoidable substances are essential for the preservation of life. The basic nutrients to be discussed in this course are proteins, carbohydrates, lipids, minerals and vitamins. Another important substance although not nutrient, but assist in proper functioning of nutrients are hormones and enzymes. Feed nutrients are vital for animals by performing the following functions (1) provision of essential elements for repairing the deteriorating cells (2) provision of raw materials for synthesis of body tissues in growth (3) serving as a source of energy for vital processes in the body, growth, work or production (4) for generating heat necessary for maintaining body temperature (5) raw material for the production of milk, meat, egg or wool as the case may be.

Objectives

At the end of this lecture, students will be able to identify the basic nutrients required for the upkeep of farm animals and be able to differentiate their fundamental roles.

Pre-Test

1. List the necessary nutrients that are indispensable to farm animals.
2. Explain the occurrence of protein, carbohydrates, lipids, minerals, vitamins, hormones and enzymes in nature.

CONTENT

This lecture will discuss what, why, when and how of proteins, carbohydrates, lipids, minerals, vitamins, hormones and enzymes.

Proteins

The major component of soft tissues and internal organs, e.g. liver, kidney, heart, lungs, etc of animal body is protein. For growth and repair to be sustained in animal, there must be transformation of food protein into body protein. Proteins are complex compounds, each molecule being composed of a considerable number of amino acids. The animals build their body proteins primarily from the amino acids absorbed from the digested dietary proteins. The only consideration for the absorption of protein is when it has broken down into amino acids. The terms essential and non-essential amino acids means that the essential amino acids have to be supplied from external sources. The non-essential amino acids missing in the diet can be produced in the body from other sources. In the preceding lectures of this course, we shall somehow look into the structures and properties of amino acids and protein. The lecture will also consider some nitrogenous compounds that are not true protein, but found in plants and animals.

Carbohydrates

The principal part of food for animals is carbohydrates. However, it is suffice to say that none of the carbohydrates is found as such in the animal body, the only exceptions being glycogen and small amount of sugar. The term carbohydrate connotes the presence of carbon, hydrogen and oxygen, the latter two in the proportion as seen in water. These compounds are very important in nutrition of animals because they are the chief source of energy for the animals for maintenance, growth, production and work. They also help the animals to maintain their body temperature. Carbohydrates include sugars, starch, cellulose, hemicellulose, pectins, gums, and mucilages. Sugars are the simplest carbohydrates which are sweet and soluble in water. Starch, a polymer of glucose is a major component of animals' diet. Plants store excess food nutrients as starch, as a reserve. Starch is not soluble in water but easily broken down to sugars in a process of digestion. Cellulose is a more complex and less soluble and digestible carbohydrate. Thus, cellulose has a very limited role as a nutrient in the case of carnivorous and omnivorous animals. This lecture will bring to a deem light the chemistry of carbohydrates which will involve simple and complex structures.

Lipids

Lipids are biological substances that are soluble in organic solvents. Apart from being structural components of biological membrane, they also play a major role in the nutrition of the animal. Just as carbohydrates can be a supply of energy, lipids can also fulfil this function in a higher way. Later, we shall focus on functions of lipids and structures of some common ones.

Minerals

Minerals are significant for normal activities in farm animals. About 40 minerals have been discovered to occur naturally in the tissues of animals and plants. Out of these 40, the dietary essential minerals are those that have been shown by research to have essential metabolic roles in the body. The 27 basic dietary essential minerals include Ca, P, Mg, Na, K, Cl, S, Mn, Fe, Cu, I, Zn, F, Vn, Co, Mo, Se, Ni, Cr, Si and Sn. Part of the study on minerals shall include trace and major minerals, fundamental roles of minerals, requirements for different animals and their deficiencies.

Vitamins

Vitamins are conveniently classified into water and fat soluble vitamins. Vitamins are part of a complete diet although needed in only minute amounts but essential for animal production. Vitamins are very essential in that they cannot be produced by animals tissues at all or in sufficient quantities to supply the needs under normal circumstances.

Hormones and Enzymes

Hormones are organic compounds produced in one part of the body and then transported to other parts of the same body where they produce a response. Enzymes are molecules which catalyse biochemical reactions by acting on their substrates and converting them into products. In our subsequent lectures, we shall be detailed about the action, mode and the targets of hormones and enzymes.

Summary

The first lecture introduced you to the basic nutrients, their structures, properties and functions. It is however, a periphery of the expected. The nutrients that have been highlighted are proteins, carbohydrates and lipids, minerals and vitamins. Hormones and enzymes are not nutrients but essential for the metabolism of the nutrients afore mentioned.

Post-Test

1. List the basic nutrients that are required by farm animals.
2. What are the end products of proteins and carbohydrates?
3. State the functions of protein and carbohydrates.

Reference

Maynard, L.A. , Looshi, J.K., Hintz, H.F. and Warner, R.S. (1983). *Animal Nutrition. 7th Edition*. Published by Tata McGrar Hill Publishing Company Limited.

Amino Acids

Introduction

Protein is an indispensable nutrient required by animals for growth, replacement of deteriorating cells and generally for body health. Protein is important, but one of the essential nutrients required to uphold the body's health. Chemically, proteins are complex organic compounds that contain the same atoms as carbohydrates and lipids. The constituents are carbon, hydrogen and oxygen. However, protein, in addition to these compositions also contains nitrogen and sulphur. In this lecture, you shall be taken through the amino acids which are the smallest particles obtained when complex protein is broken down by the process of digestion.

Objectives

At the end of this lecture, students will be able to catch the glimpse of amino acids in terms of structure, properties and indispensabilities.

Pre-Test

1. What are amino acids?
2. From the structure of amino acid, list three constituents that make the structure.
3. Mention nine essential amino acids.
4. State properties of amino acids.

CONTENT

Meaning and structure of amino acids. Essential amino acids and properties of amino acids will be discussed step by step as follows:

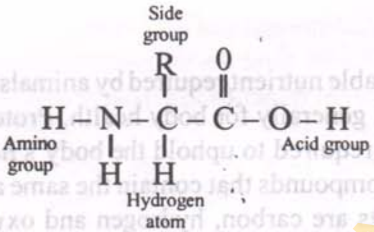
Meaning and Structure of Amino Acids

The end product of a systematically hydrolysed proteins by digestive enzymes, acids or alkalis is known as amino acids. There are well over 200 identified amino acids, out of which 20 frequently occur as components of proteins. There is no amino acid that does not have identical fundamental structure.

The structure is a carbon (C) with three groups of atoms attached to it:

1) an amino group (NH_2)
2) an acid group (COOH) and
3) a hydrogen atom (H)

Essentially, carbon atoms need to possess four bonds but the differences between one amino acid to the other is the fourth attachment.



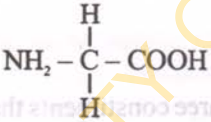
Amino acid structure

Common Amino Acids

As mentioned at the beginning of this lecture, there are 20 common amino acids that proteins are made up of. In order to understand it better, the amino acids are classified into:

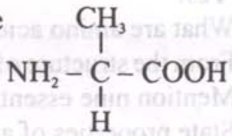
1. Monoamino-monocarboxylic acids. These include:

(a) Glycine



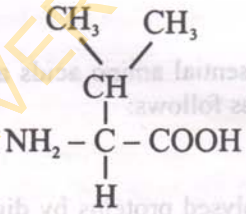
$$NH_2-\overset{\overset{H}{|}}{\underset{\underset{H}{|}}{C}}-COOH$$

(b) Alanine

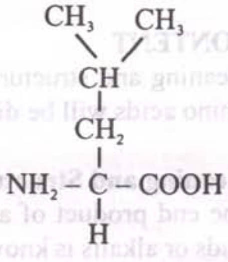


$$NH_2-\overset{\overset{CH_3}{|}}{\underset{\underset{H}{|}}{C}}-COOH$$

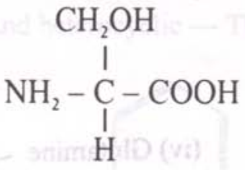
(c) Valine



(d) Leucine

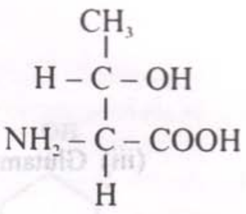


(e) Serine



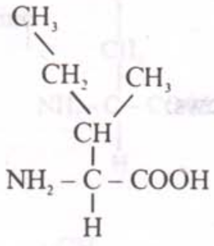
$$\mathrm{NH_2-\overset{\displaystyle CH_2OH \atop |}{\underset{\displaystyle | \atop H}{C}}-COOH}$$

(f) Threonine



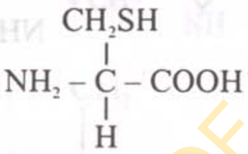
$$\begin{array}{c} \mathrm{CH_3} \\ | \\ \mathrm{H-C-OH} \\ | \\ \mathrm{NH_2-C-COOH} \\ | \\ \mathrm{H} \end{array}$$

(g) Isoleucine



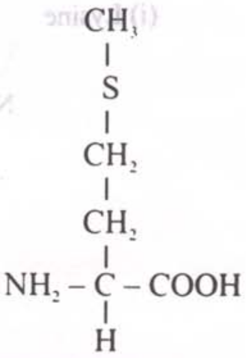
2. Sulphur-containing amino acids. Examples are:

(i) Cysteine



$$\mathrm{NH_2-\overset{\displaystyle CH_2SH \atop |}{\underset{\displaystyle | \atop H}{C}}-COOH}$$

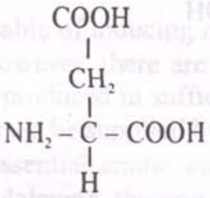
(ii) Methionine



$$\begin{array}{c} \mathrm{CH_3} \\ | \\ \mathrm{S} \\ | \\ \mathrm{CH_2} \\ | \\ \mathrm{CH_2} \\ | \\ \mathrm{NH_2-C-COOH} \\ | \\ \mathrm{H} \end{array}$$

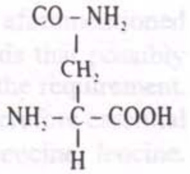
3. Monoamino-dicarboxylic acids

(i) Aspartic acid



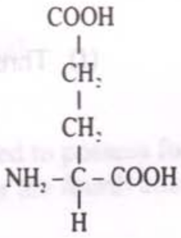
$$\begin{array}{c} \mathrm{COOH} \\ | \\ \mathrm{CH_2} \\ | \\ \mathrm{NH_2-C-COOH} \\ | \\ \mathrm{H} \end{array}$$

(ii) Asparagine



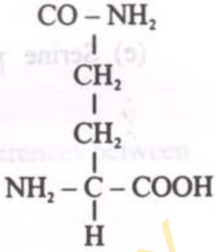
$$\begin{array}{c} \mathrm{CO-NH_2} \\ | \\ \mathrm{CH_2} \\ | \\ \mathrm{NH_2-C-COOH} \\ | \\ \mathrm{H} \end{array}$$

(iii) Glutamic acid



$$\begin{array}{c} \mathrm{COOH} \\ | \\ \mathrm{CH_2} \\ | \\ \mathrm{CH_2} \\ | \\ \mathrm{NH_2-C-COOH} \\ | \\ \mathrm{H} \end{array}$$

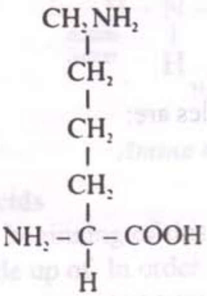
(iv) Glutamine



$$\begin{array}{c} \mathrm{CO-NH_2} \\ | \\ \mathrm{CH_2} \\ | \\ \mathrm{CH_2} \\ | \\ \mathrm{NH_2-C-COOH} \\ | \\ \mathrm{H} \end{array}$$

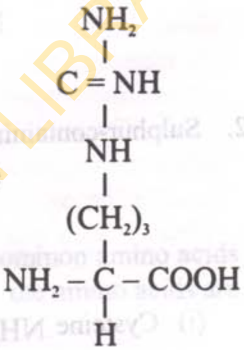
4. Basic amino acids. They are as follows:

(i) Lysine



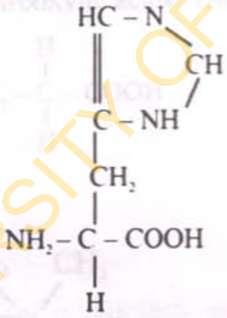
$$\begin{array}{c} \mathrm{CH_2NH_2} \\ | \\ \mathrm{CH_2} \\ | \\ \mathrm{CH_2} \\ | \\ \mathrm{CH_2} \\ | \\ \mathrm{NH_2-C-COOH} \\ | \\ \mathrm{H} \end{array}$$

(ii) Arginine



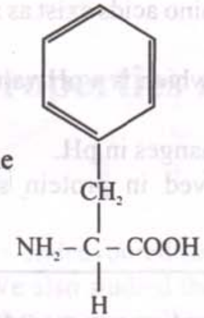
$$\begin{array}{c} \mathrm{NH_2} \\ | \\ \mathrm{C=NH} \\ | \\ \mathrm{NH} \\ | \\ \mathrm{(CH_2)_3} \\ | \\ \mathrm{NH_2-C-COOH} \\ | \\ \mathrm{H} \end{array}$$

(iii) Histidine

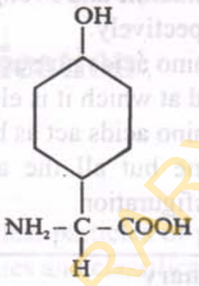


5. Aromatic and heterocyclic — These include:

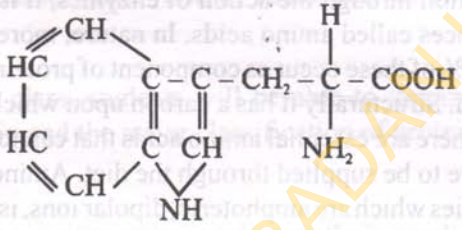
a) Phenylalanine



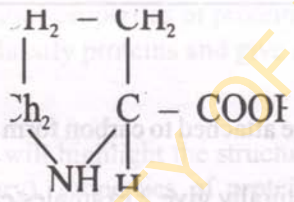
b) Tyrosine



c) Tryptophan



d) Proline



Essential Amino Acids

The animal's body is capable of inducing more than 50% of the aforementioned amino acids for itself. However, there are basic nine amino acids that possibly cannot be synthesized or produced in sufficient amount to meet the requirement. These nine amino acids must be supplied by the diet. They are therefore essential amino acids. The nine essential amino acids are histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine.

Properties of Amino Acids

1. Amino acids are amphoteric which exhibits dual properties of both basic and acidic

2. In acqueous solution, amino acids exist as dipolar ions.
3. In alkaline and strong acid solutions, amino acids exist as an anion and a cation respectively.
4. Amino acids possess isoelectric point which is a pH value for a given amino acid at which it is electrically neutral.
5. Amino acids act as buffers, resisting changes in pH.
6. None but all the amino acids involved in protein structure have an L-configuration.

Summary

Proteins are complex organic compounds that contain C,H,O,N and S. when protein undergo digestion through the action of enzymes, it is broken down to a simpler food substances called amino acids. In nature, more than 200 amino acids exist but only 10% of these occur as component of proteins and are known as common amino acid. Structurally it has a carbon upon which three groups of atoms are anchored. There are essential amino acids that cannot be produced by the body itself but have to be supplied through the diet. Amino acids generally possess certain properties which are amphoteric, dipolar ions, isoelectric, buffers and L-configuration.

Post-Test

1. a) What are amino acids?
   b) List the three groups of atoms that are attached to carbon form structure for amino acids.
2. Classify amino acids into five and structurally give 2 examples each.
3. List essential amino acids, state why they are vital than others.
4. Enumerate properties of amino acids.

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Structure, Properties and Classification of Proteins

Introduction

In our last lecture, we endeavoured to consider the smallest particles of protein called amino acids. We also studied the structure, properties and classification of amino acids. In this chapter, we will proceed to appraise protein in its entirety. It is essential to discuss its framework, its characteristics and various classes.

Objectives

By the end of this class, students will be able to itemize structures of protein, properties of protein and the major classification of protein.

Pre-Test

1. List four structures of protein and discuss their peculiarities.
2. State various properties of protein.
3. Briefly classify proteins and give at least 2 examples of each.

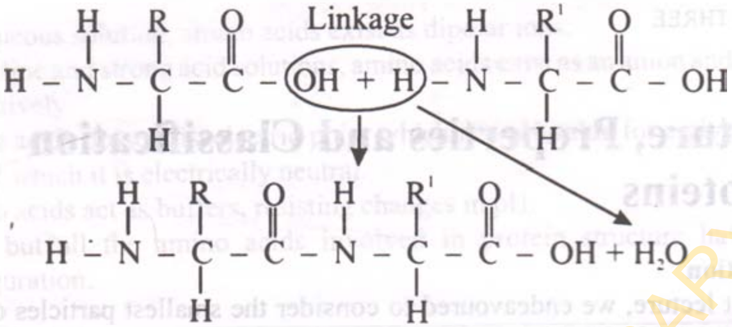
CONTENT

This chapter will highlight the structure of proteins (primary, secondary, tertiary and quaternary), properties of proteins and classification of proteins (simple, conjugated and derived).

Structure of Protein

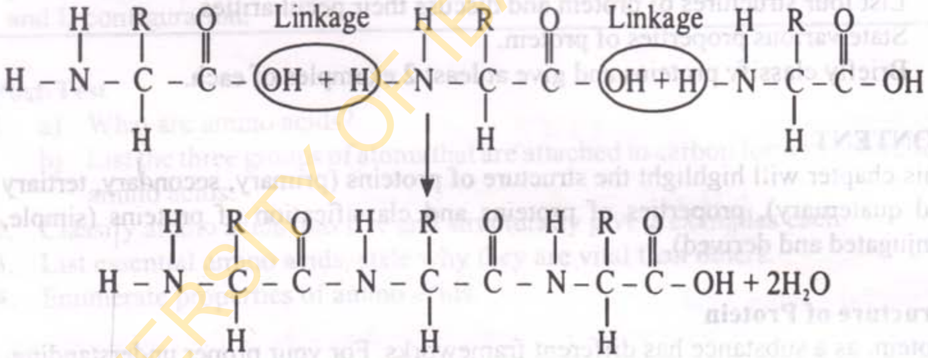
Protein, as a substance has different frameworks. For your proper understanding, we shall present that structure of proteins under primary, secondary, tertiary and quaternary proteins.

i) **Primary Structure:** This structure comes to existence as a consequence of the linkage between the α - Carboxyl of one amino acid and the α - amino group of another acid.



$$H-\overset{H}{N}-\underset{H}{\overset{R}{C}}-\overset{O}{\overset{\|}{C}}-OH + H-\overset{H}{N}-\underset{H}{\overset{R'}{C}}-\overset{O}{\overset{\|}{C}}-OH \longrightarrow H-\overset{H}{N}-\underset{H}{\overset{R}{C}}-\overset{O}{\overset{\|}{C}}-\overset{H}{N}-\underset{H}{\overset{R'}{C}}-\overset{O}{\overset{\|}{C}}-OH + H_2O$$

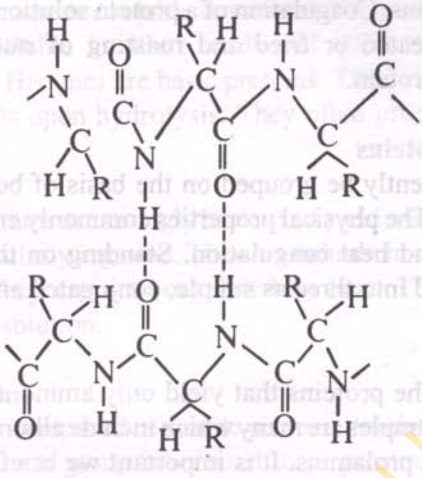
This type of linkage is known as peptide linkage and it is a linkage formed between two amino acids followed by the elimination of water as revealed in above structures. In the illustrated structure, a dipeptide was formed from two amino acids. Numerous amino acids can be married together using this addition procedure. When this happened with the removal of one molecule of H_2O at every linkage, the polypeptides are produced.



$$H-\overset{H}{N}-\underset{H}{\overset{R}{C}}-\overset{O}{\overset{\|}{C}}-OH + H-\overset{H}{N}-\underset{H}{\overset{R}{C}}-\overset{O}{\overset{\|}{C}}-OH + H-\overset{H}{N}-\underset{H}{\overset{R}{C}}-\overset{O}{\overset{\|}{C}}-OH \longrightarrow H-\overset{H}{N}-\underset{H}{\overset{R}{C}}-\overset{O}{\overset{\|}{C}}-\overset{H}{N}-\underset{H}{\overset{R}{C}}-\overset{O}{\overset{\|}{C}}-\overset{H}{N}-\underset{H}{\overset{R}{C}}-\overset{O}{\overset{\|}{C}}-OH + 2H_2O$$

Polypeptide

ii) **Secondary Structure** – This structure shows the conformation of the chain of amino acids emanating due to production of hydrogen bonds between the imido (NH) and carboxyl groups of adjacent amino acids as illustrated below:



iii) **Tertiary Structure** — This structure is formed as a result of further interraction of secondary structure through the R groups of the amino acid residues. Such emanated interraction predisposes polypeptide chain to folding and bending.

iv) **Quaternary Structure** — Proteins have this structure if they contain more than one polypeptide chain. The agents that equilibrate these combinations are hydrogen bonds and salt bonds produced between residues on the surfaces of polypeptide chains.

Properties of Proteins

1. **Colloidal** — Proteins are peculiar in their water solubility. Keratin and albumins are insoluble and soluble proteins respectively. Soluble proteins can be precipitated from solution and such precipitation can in turn be redissolved.

2. **Amphoteric** — All proteins possess a certain amount of free amino and carboxyl groups, either as terminal units or in the side-chain of amino acid residues.

3. **Denaturation** — All proteins can be altered or dephased from their natural occurrence. It is a chemical, physical and biological alteration of a unique

structure of proteins. Coagulation of a protein solution upon heating, shrinking of meat when heated or fried and roasting of nuts are few examples of denaturation of protein.

Classification of Proteins

Proteins can conveniently be grouped on the basis of both physical (shape) and chemical properties. The physical properties commonly employed for grouping are those of solubility and heat coagulation. Standing on these two characteristics; proteins are classified into three as simple, conjugated and derived proteins.

A. Simple Proteins

Simple proteins are the proteins that yield only amino acids or their derivatives when hydrolysed. Examples are many which include albumins, globulins, glutelins, albminoids, histones, prolamins. It is important we briefly examine these simple proteins.

i) ***Albumins*** — Soluble in water and coagulable by heat. They are found both in plants and animals, e.g. myosin of muscle, serum albumin of blood and lactalbumin of wheat.

ii) ***Globulins*** — These are not soluble in pure water but could be dissolved in solution of alkaline and acid. They are heat coagulated. They generally contain glycine. Globulin constitute an important and widely distributed group of animal and plant proteins. For example, ovoglobulin of egg yolk, myosin of muscle, phaseolin of beans, legumins of peas and arachin of peanuts.

iii) ***Glutelins*** — Are all plant proteins and soluble in very dilute acids and alkalis but they are insoluble in natural solvents.

iv) ***Prolamins*** — Prolamins are soluble in alcohol but insoluble in water or neutral solvents. These proteins generally yield proline and amide nitrogen upon hydrolysis but are deficient in lysine. Prolamins are plant proteins found principally in seeds, e.g. zein of corn, hadein of barley, gleaden of wheat.

v) ***Albuminoids*** — It is the least soluble of all the proteins. They are generally insoluble in water, dilute acids, alkalis and alcohol. They are entirely animal protein and are the chief constituents of skeletal structures such as hair, horn, hoof, and nails. They are also constituents of supporting and connecting of fibrous tissues and of the cartilage and bone.

vi) ***Histones*** — The proteins are soluble in water and insoluble in dilute ammonia. They are readily soluble in dilute acids and alkali. They are not readily coagulated by heat. Histones are basic proteins. They yield a large proportion of basic amino acids upon hydrolysis. They often precipitate other proteins from solution.

vii) ***Protamins*** — Protamins are strongly basics and yield mainly basic amino acids on hydrolysis particularly arginine. They are soluble in water, dilute ammonia acid and alkalis. They are not coagulated by heat. They precipitates other proteins from their solution.

B. Conjugated Proteins

Conjugated proteins are composed of simple proteins combined with non-proteins substance. The non-protein group is referred to as prosthetic group or addition group. The types of conjugated proteins include the following:

1) ***Nucleo proteins*** — They composed of simple basic protein (protamin or histone) in salt with nucleo acid or nucleic. They are proteins of cell and apparently the chief constituents of chromatin. These are the most abundant in tissues of both plants and animals, having a large proportion of nucleic materials such as yeast, thymus and other glandular organs.

2) ***Mucoproteins or mucoids*** — The mucoproteins are composed of simple proteins combined with mucopolysaccharide such as hyaluronic acid, chomdrotin sulphates. They generally contain large amount of N-acetylated henosamine and in addition + or - of such substances are uronic acid, sialic acid and monosaccarid. Water soluble mucoprotein have been obtained from human urine, serum and egg white. Each water soluble mucoprotein are not easily denatured by heat or readily precipitated by agents such as picric acid and trichloro acetic acid.

3) ***Chromoproteins*** — These proteins are composed of simple proteins united with coloured prosthetic group. Many proteins of important biological function belongs to this group. Examples of chromoproteins are:
   a) Haemoglobin:- Respiratory proteins in which the prosthetic group is iron containing prophysm called EME.
   b) Cytochromes:- These are cellular of oxidation, reduction protein in which the prosthetic group is also HEME.

c) Flavoproteins:-. They are cellular oxidation-reduction proteins in which the prosthetic group are riboflavin.

d) Visual purple of the retina:- It is a chromoprotein in which the prosthetic group is carotenoid pigment.

4) ***Phosphoproteins*** — Phosphoric acid is the prosthetic group of phosphoprotein. Phosphosenine has been isolated from casein (milk) and vitellin (egg).

5) ***Lipoproteins*** — Lipoproteins are formed by combination of proteins with lipid such as lecithin, cephalin, fatty acid, etc. phospholipid proteins are widely distributed in plants and animals, milk, and in chloroplast of plant.

6) ***Metalloproteins*** — This is a large group of enzyme proteins which contain metallic element such as Fe, Co, Mn, Zn, Cu, Mg, etc. which are parts of their essential structures.

C. Derived Protein

This class of proteins as the name implies includes those substances formed from simple and conjugated proteins. It is the least well defined of the protein group. Derived proteins are sub-divided into primary and secondary.

Primary Derived Protein

This protein derivatives are formed by processes which cause only slight changes in the protein molecules and its properties. There is little or no hydrolytic cleavage of peptide bond. The primary derived proteins are synonymous with denatured protein. Examples of primary derived proteins are:

1) ***Proteans*** — They are insoluble product formed by the incipient action of H_20, very dilute acids and enzymes. They are particularly formed from certain globulins and differ from globulins being insoluble in dilute salt solution.

2) ***Metaproteins*** — They are formed by the action of acids and alkalis upon protein. They are generally soluble in very dilute acid and alkalis but insoluble in neutral solvent.

3) ***Coagulated proteins*** — These are the soluble proteins formed by the action of heat or alcohol upon natural protein.

Secondary Derived Protein

The substances are produced in the continuous hydrolytic cleavage of the peptide unions of protein molecules. They represent a great complexity of protein molecules of different sizes and amino acid composition. They are grouped into proteoses, peptones, peptides according to average molecular complexity. Each group is composed of many substances.

1) ***Proteoses*** — These are hydrolytic product of proteins which are soluble in water and not coagulated by heat and are precipitated from their solution by saturation with $(NH_4)_2SO_4$.
2) ***Peptones*** — Peptones are hydrolysed in water. They are not coagulated by heat and not precipitated by saturation with $(NH_4)_2SO_4$.
3) ***Peptide*** — They are composed of only a relatively few amino acid united through peptide bonds. They are named according to the number of amino acid group present as di, tri, tetra, penta, — peptide, etc. They are water soluble, not coagulated by heat, not salted out of solution and are often precipitated by phosphotungstic acid.

Summary

Protein possesses different structures in which it can be identified. There are four basic structures that include primary, secondary, tertiary and quaternary proteins. Proteins are endowed with distinctive characteristics which ranges from colloidal, amphoteric and denaturation. For conveniences, proteins are classified into simple proteins (albumins, globulins, glutelins, prolamins, albuminoids, histones, and protamins), conjugated proteins (nucleo proteins, mucoproteins, chromoproteins, phosphoproteins, lipoproteins, metalloproteins) and derived proteins (primary and secondary derived proteins).

Post-Test

1. Enumerate structures of proteins.
2. Identify the inherent characteristics of proteins.
3. Discuss the following with specific examples:
   a) Simple proteins
   b) Conjugated proteins
   c) Derived proteins

References

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LECTURE FOUR

Non-Protein Nitrogenous Compound

Introduction

There are true proteins as earlier discussed. These are the proteins that are routinely analysed for in chemical analysis. However, there are some nitrogenous compounds that are not true protein, but found in plants and animals. They are classified as non-protein nitrogenous (NPN) compounds. Certain amino acids such as, alanine, glutamic acid, serine, aspartic acid, glycine and proline belong to NPN. Some other NPN compounds are lipids, amines, amides, purines, pyrimidines, nitrates and alkaloids. Also, numerous vitamin B complex possess nitrogen in their structure, e.g. thiamine, riboflavin, Niacin, pantothenic acid, Vitamin B_6, etc.

Objectives

At the end of this chapter, students will be able to differentiate the difference between true protein and non-protein nitrogen.

Pre-Test

1. State examples of true protein
2. Define non-protein nitrogenous compounds.
3. List various examples of NPN compounds and where they are obtained.

CONTENT

Our discussion in this lecture today will revolve around specific and common NPN compounds to include (1) Amines, (2) Amides, (3) Nitrates, (4) Alkaloids and nucleic acids.

Amines

Amines occur in nature as fundamental compounds that are available in various animal and plant tissues. In decayed or decaying organic matter, sizeable number of amines occur as toxic decomposition products. Through the process of decarboxylation of amino acids, many of the micro-organisms are capable of yielding amines. Under certain circumstances, these may be produced in the rumen of any ruminants that could culminate in physiological symptoms. In a poorly prepared silages for pasture preservation, which clostridia predominated the fermentation, significant amount of amines are contained. Betaine is a tertiary amine whose occurrence is in sugar beet, and it is this amine present that is behind the fish-like aroma commonly characterised the commercial extraction of sugar from beet. Likewise, in the animal body, especially dairy, betaine is capable of transforming into, trimethyl-amine, and it is this which, gives the fishly smell to milk produced by cows that have been given excessive amount of sugar beet by-products.

Amides

An essential amides that occur as components of proteins are asparagine and glutamine, which are derivatives of certain amino acids. They occur as free amides and play an important role in transamination reactions. Urea is an amide which is the main end-product of nitrogen metabolism in mammals. In human beings and other primates, uric acid is the end product of purine metabolism and is found in the urine. In birds, uric acid is the principal end-product of nitrogen metabolism and thus corresponds, in its function, to urea in mammals.

Nitrates

Nitrate is present in certain plants and naturally non-toxic except by reduction to nitrite in a favourable rumen condition that becomes toxic. Oat hay poisoning is traced to the concentrated amounts of nitrate present in fresh green oats. There were reports that established the high levels of nitrate in herbage given heavy dressings of nitrogenous fertilisers.

Alkaloids

Alkaloids are present only in some plants and many of them have poisonous properties. Their presence is limited to a few orders in the dicotyledons. Some important alkaloids occurring in plants are quinine (cinchona bark), nicotine (tobacco), conine (hemlock), atropine (deadly nightshade), cocaine (leaves of coca plant), solanine (unripe potatoes and potato sprouts), ricinine (castor plant seeds).

Nucleic acids

Nucleic acids are high molecular weight compounds consisting of nitrogenous compounds (purines and pyrimidines), a pentose (ribose or deoxyribose) and phosphoric acid. Nucleic acids are the bedrock in plants and animals as a reservoir of genetic information, and they are the means by which this information is utilised in the synthesis of proteins.

1) The main pyrimidines found in nucleic acids are cystosine, thymine and uracil.
2) Adenine and guanine are the principal purine bases present in nucleic acids.
3) Phosphoric acid — if nucleotides such as adenosine are esterified with phosphoric acid they form nucleotides, e.g. Adenosine monophosphate (AMP).
4) Ribose — Nucleotides containing ribose are termed ribonucleic acids (RNA) while those containing deoxyribose are known as deoxyribonucleic acids (DNA).

Summary

There are non–protein nitrogenous (NPN) compounds that are present in plant and animals. Some of these NPN are highly poisonous primarily or secondarily. For example, amine is only poisonous or toxic under decomposition or fermentation of organic matter (OM). Also, nitrates in certain plants is not toxic but toxic as nitrite in a favourable rumen condition. On the other hand, certain NPN, e.g. alkaloids are primarily toxic in some plants, e.g. cocaine in the leaves of coca plant.

Post-Test

1. What are non-protein nitrogenous (NPN) compounds?
2. List those NPN that are secondary poisonous and state how?
3. Explain why nucleic acids formed the 'bedrock' of living organisms.

References

Lehninger, A.L. (1982). *Principles of Biochemistry. New* York: Worth Publ.
McDonald, P., R.A. Edwards, J.F.D. Greenhalgh (1987). *Animal nutrition.* Fourth edition. London: ELBS,

LECTURE FIVE

The Chemistry of Carbohydrates I

Introduction

Carbohydrates make up most of the organic structure of all plants, as well as being present to some extent in all animals. Carbohydrates in plants are produced by the processs of photosynthesis (the most important chemical reaction in nature). During photosynthesis radiant energy (solar energy) from the sun is captured by chlorophyll and changed to chemical energy, which in turn supports formation of glucose from carbon dioxide and water. This overall reaction can be represented by the equation below. However, the intermediate biochemical reactions involved are much more complex and should be left for an advance course. The animal life is basically dependent on the process of photosynthesis.

$$6C0_2\ 6H_2O \xrightarrow[Chlorophyll]{sunlight} \underset{(Sugar)}{C_6 H_2 0_6}\ 60_2$$

Objective

In this course, we shall concentrate on the different courses of carbohydrates, and their chemical structures and functions.

Pre-Test

Discuss the types and functions of carbohydrates.

CONTENT

What are Carbohydrates?

Carbohydrates simply put, means hydrated carbon because many of them can be represented by the simple stoichoimetric formula $(CH_2O)_n$. This formula is an oversimplification because many carbohydrates (saccharides) are modified, and contain amino, sulphate and phosphate groups.

Generally speaking, carbohydrates are a group of organic compounds that include sugar and related compounds. However, chemically, carbohydrates are polyhydroxy aldehydes and ketones, or substances which yield them (aldehydes and ketones) upon hydrolysis. In this respect, the group termed carbohydrates include sugars, starches, cellulose, gums, pectins, saponins, glucosinolates, cyanogenic glucosides, lectins, glycogen, chitin, etc.

Importance of Carbohydrates

Carbohydrates are extremely versatile molecules essential to every kind of living organism. Carbohydrates are among the most abundant constituents of plants and animals. They serve the following functions:

i) As major storehouse of chemical energy, i.e. provision of energy for carrying out life processes.

ii) They serve as sources of raw materials for the chemical synthesis, e.g. milk is synthesis from two kinds of carbohydrates namely galactose and glucose.

iii) They serve as supportive structural components in plants, e.g. cellulose, lignin, hemicellulose, etc.

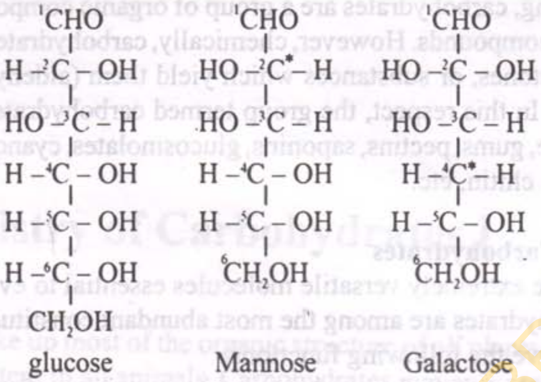
iv) Carbohydrates are essential in the genetic control of development and growth of living cells. Ribonucleic acid (RNA) and deoxyribonucleic acid (DNA) the genetic materials contain ribose sugar, a form of carbohydrate.

v) Some kinds of carbohydrates protect plants against infections, e.g. polyphenolics, saponins, etc.

Some General Properties of Carbohydrates

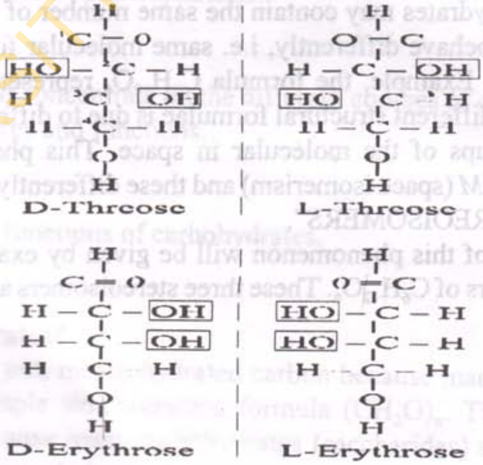
Many of the carbohydrates may contain the same number of atoms and the same kind of groups yet behave differently, i.e. same molecular formula but different structural formulae. Example, the formula $C_6H_{12}O_6$ represents sixteen different simple sugars. The different structural formulae is due to different arrangement of the constituent groups of the molecular in space. This phenomenon is called *STEREOISOMERISM* (space isomerism) and these differently arranged sugars are referred to as "STEREOISOMERS".

An illustration of this phenomenon will be given by examining three of the sixteen stereoisomers of $C_6H_{12}O_6$. These three stereoisomers are glucose, mannose and galactose.



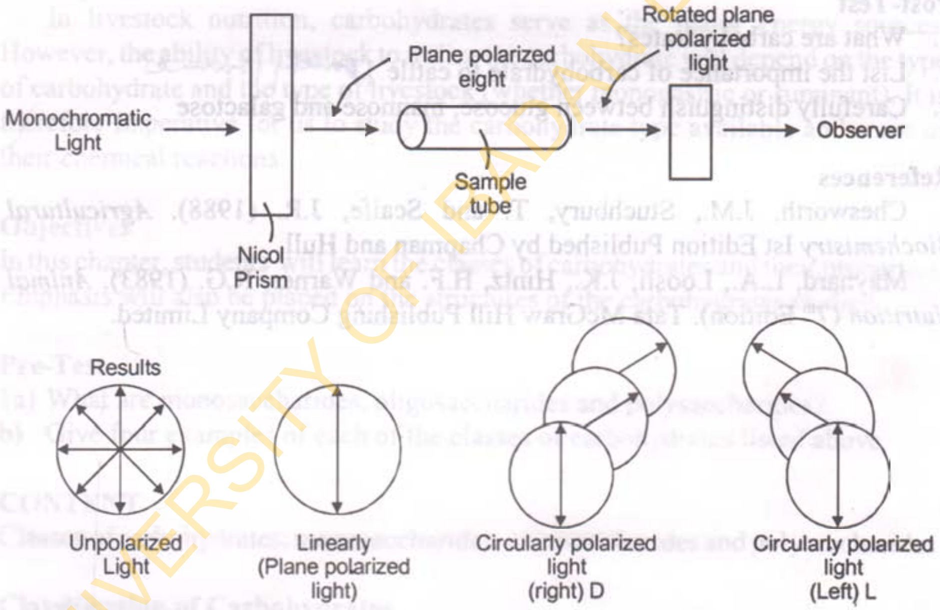
A closer look at these structures of mannose and galactose will show that they (mannose and galactose) would have assumed the structure of glucose but for a change in the positions of OH group on carbon 2 and 4 for mannose and galactose respectively. The carbon atoms involved are in asterisks. Other structures (stereoiserms) do not exist naturally in nature.

Carbohydrates also exhibit a phenomenon called *ENANTIOMERS.* Enantiomers are compounds with the same chemical formula but can exist in two forms — one of the forms being a mirror image of the other. This phenomenon is common with monosaccharides because they (monosaccharides) tend to have more than one chiral carbon, which results in their having two types of stereoisomers. An example of this stereoisomer can be illustrated with the monosaccharides, Threose and Erythrose



The enantiomers for Threose and Erythrose are arranged according to the manner in which the substituents are arranged about the asymmetric carbon atoms. The naming by L and D (for "dextrorotatory" and "Levorotatory") are according to a convention established by Emil Fisher.

The carbohydrates also exhibit the property of optical activity and therefore exist as optical isomers. When carbohydrates are placed in a *POLARIMETER* (an instrument for studying the interaction of polarized light with optically active substances (Fig. 1) the resulting light is either circularly polarized to the right or left. When the plane polarized light is rotated clockwise (i.e. to the right) the substance is classified as DEXTRORATORY (d-), but when rotated counterclockwise (anticlockwise) (i.e to the left), the substance is termed LEVOROTATORY (L-). However, when equal mixtures of d and L substances are mixed (dl) the resultant (RACEMIC) is optically inactive.



Summary

Carbohydrates make up most of the organic structures of all plants and to some extent in all animals. Carbohydrates are manufactured by process of photosynthesis—the most important chemical reaction in nature.

Chemically carbohydrates are polyhydroxy aldehydes and ketones, or substances which yield aldehydes and ketones upon hydrolysis. The term carbohydrate includes sugars, starches, cellulose, gums, pectins, saponins, glucosinolates, etc.

Functionally, carbohydrates serve as a major storehouse of energy, raw materials for synthesis of milk and also supportive structural components. In addition, carbohydrates are essential in synthesis of RNA and DNA — the genetic materials. Carbohydrates exhibit stereo isomerism.

Post-Test

1. What are carbohydrates?
2. List the importance of carbohydrate to cattle / poultry / swine
3. Carefully distinguish between glucose, mannose and galactose

References

Chesworth, J.M., Stuchbury, T. and Scaife, J.R. (1988). *Agricultural Biochemistry* Ist Edition Published by Chapman and Hull.

Maynard, L.A., Loosli, J.K., Hintz, H.F. and Warner, R.G. (1983). *Animal Nutrition* (7th Edition). Tata McGraw Hill Publishing Company Limited.

The Chemistry of Carbohydrates II

Introduction

Carbohydrates play an important role in the supply of energy, structural rigidity and formation of RNA and DNA in living organisms (plants and animals). The carbohydrates come in different forms (classes) and the ability of carbohydrates to carry out the above mentioned functions depends on the type (class) of carbohydrate.

In livestock nutrition, carbohydrates serve as the major energy sources. However, the ability of livestock to utilize the carbohydrate will depend on the type of carbohydrate and the type of livestock (whether monogastric or ruminant). It is therefore imperative for us to study the carbohydrate type available and some of their chemical reactions.

Objectives

In this chapter, students will learn the classes of carbohydrates and their properties. Emphasis will also be placed on the structures of the carbohydrates studied.

Pre-Test

1a) What are monosaccharides, oligosaccharides and polysaccharides?
b) Give four examples of each of the classes of carbohydrates listed above.

CONTENT

Classes of carbohydrates; monosaccharides, oligosaccharides and polysaccharides.

Classification of Carbohydrates

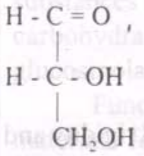
Carbohydrates are classified into three broad groups, namely:

I. Monosaccharides
II. Oligosaccharides
III. Polysaccharides

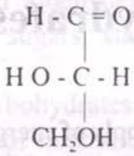
We will now take each of these carbohydrates (above) and discuss them in details.

The type of carbonyl group is denoted by the prefix of aldo-for an aldehyde and keto-for a ketone, e.g. glyceraldehyde is an aldo-triose. The structures of some common monosaccharides are given below:

Trioses (C_3)

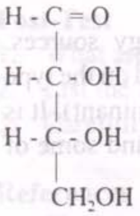


D-glycerose



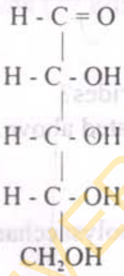
L-glycerose

Tetroses (C_4)

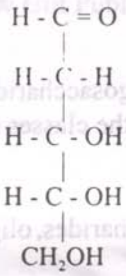


D-erythrose

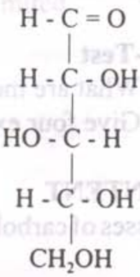
Pentoses (C_5)



D-Ribose
(RNA)



2-Deoxy-D-Ribose
(DNA)



D-xylose
(Hemicellulose)

I. Monosaccharides

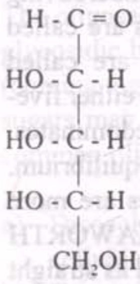
The monosaccharides are also referred to as simple or monomeric sugars. The monosaccharide is the fundamental unit from which all carbohydrates are formed. Monosaccharides are therefore the simplest carbohydrates.

The monosaccharide can be represented by the empirical formular $(CH_2O)_n$ when 'n' a whole number is equal or greater than the value 3. The smallest molecules usually regarded as monosaccharides are the trioses with n = 3 (The suffix -ose is commonly used to designate compounds as saccharides).

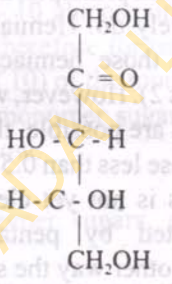
Monosaccharides containing 2 to 10 carbon atoms have been synthesized, and many occur in nature.

Naming of Sugars

The chemical names of sugars and many complex carbohydrates end with the suffix-ose. They are also named on a basis of the number of carbon atoms that they contain; tri- for three, and tetra-, petra, hex-, and hept- for 4, 5, 6 and 7, respectively.

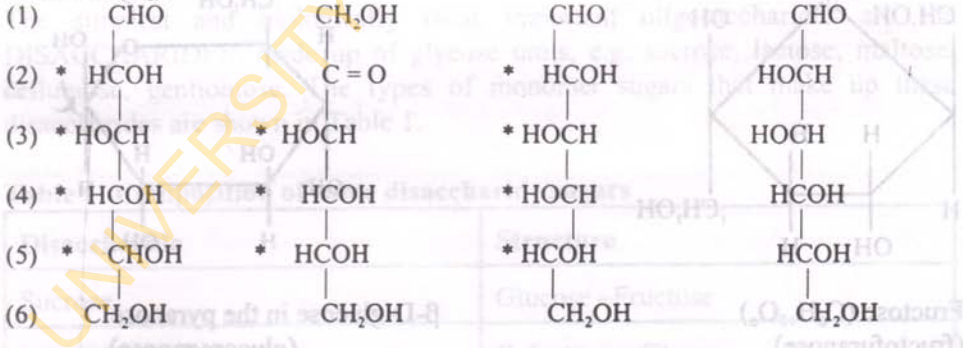


L - Arabinose
(Gums)



D - Xylulose
(Phosphogluconate pathway)

Hexoses (C_6)

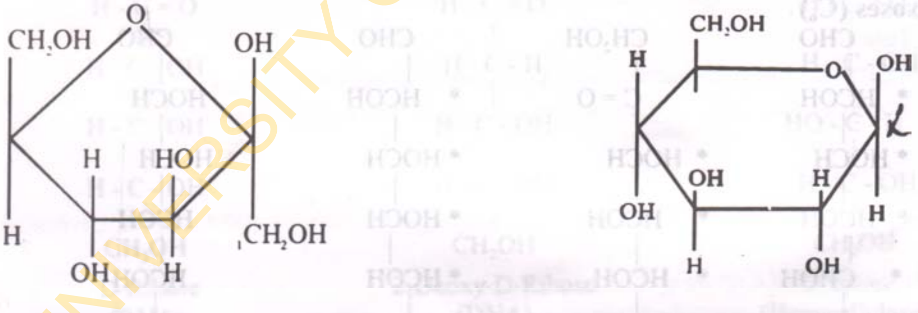


D-glucose D-fructose D-galactose D-mannose

Note that all the hexoses above are aldehyde except fructose which is a ketone. Because of the presence of asymmetric carbon atoms (labelled with an asterisk) a number of stereoisomers are possible.

Some monosaccharides occur in nature while others are synthetic. The hexoses and pentoses are the most important of the simple sugars. The monosaccharides or simple sugars are generally well-crystallined solids, soluble in water, and have more or less sweet taste.

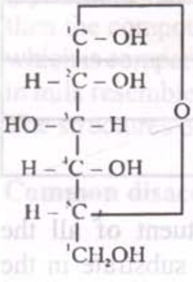
Pentoses and hexoses with 5 and 6 carbon atoms respectively have the potential to form very stable ring structures via internal HEMIACETAL formation. The bond angles characteristics of carbon and oxygen bonding are such that rings containing fewer than five atoms are strained to some extent, whereas fire- or six-numbered rings are easily formed. In principle, aldotetroses can also form five-numbered ring structure, but they rarely do. Hemiacetals with five-membered rings are called FURANOSES, while those hemiacetals with six-membered rings are called PYRANOSES (figures 2). However, we should note that in cases where either five- or six-membered rings are possible, the six-membered ring usually predominates. For example, for glucose less than 0.5% of the furanose forms exist at equilibrium. Why? Reason for this is not yet clear. But furanoses and pyranoses are more realistically represented by pentagons or hexagons as in HAWORTH CONVENTION. In another way the structures can also be represented as straight chain showing the acetal bonding as described in the FISHER PROJECTION (Figure 3).



Fructose ($C_6H_{12}O_6$)
(fructofuranose)

β-D-glucose in the pyranose
(glucopyranose)

Fig. 2: Rug structure of six carbon atom compounds



∝ – D – Glucose
(Fisher projection)

II. Oligosaccharides

The oligosaccharides contain sugars with 2 - 10 glucose units joined together by glycosidic bonds. The oligosaccharides are therefore formed by the combination (coming together) of 2 or more (maximum of 10) of the monomers. The monomer sugars may be of same sugars or different monomer sugars. Examples of some common oligosaccharides are mentioned below:

a) Disaccharides — made up of 2 monomer sugars, e.g. sucrose, maltose, cellubiose.
b) Trisaccharides — made up of 3 monomer sugars, e.g. raffinose
c) Tetrasaccharides — made up of 4 monomer sugars, e.g. stachyose.
d) Pentasaccharides — made up of 5 monomer sugars, e.g. verbascose.

The simplest and biologically most important oligosaccharides are the DISACCHARIDES, made up of glycose units, e.g. sucrose, lactose, maltose, cellubiose, gentiobiose. The types of monomer sugars that make up these disaccharides are shown in Table 1.

Table 1: Composition of some disaccharide sugars

Disaccharide	**Structure**
Sucrose	Glucose –Fructose
Lactose	Galactose – Glucose
Trehalose	Glucose – Glucose

Maltose	Glucose – Glucose
Cellubiose	Glucose – Glucose
Gentiobiose	Glucose – Glucose

A look at Table 1 shows that glucose appeared as a constituent of all the disaccharide. This underscores the importance of glucose as a substrate in the nutrition of plants and animals. Secondly, a look at maltose, cellubiose and gentiobiose showed that these disaccharides contain only glucose units. The question now is that how can two glucose units combine to give three different products. This may appear confusing at first. A little explanation is therefore needed at this stage. This will depend firstly on whether the connecting sugars are α or β type and secondly it will also depend on the points at which the sugars are connected to each other. These points are illustrated by discussing how the disaccharides are formed from two units of monomers.

The disaccharides derive their name from the fact that they are a combination of two molecules of monosaccharides. Their general formular, $C_{12}H_{22}D_{11}$ indicates that one molecule of water has been eliminated as two monosaccharides combine

$$C_6H_{12}O_6 + C_6H_{12}O_6 \xrightarrow{\uparrow H_2O} C_{12}H_{22}O_{11}$$

Formation of Disaccharides

Two molecules of simple sugars (monomers) are linked together by an acetal to form a disaccharide. The two simple sugars may either be similar or different. The following features therefore distinguish one disaccharide from another.

i) The two specific sugars involved and their stereoconfiguration. (Remember the stereoisomerism discussed in lecture I).

ii) the carbons involved in the linkage. Most common linkages are 1 → 1, 1 → 2, 1 → 4 and 1 → 6.

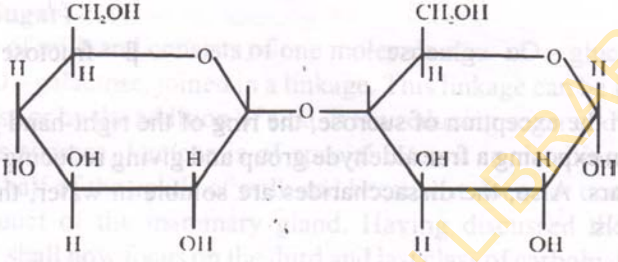
iii) the order (arrangement) of the two monomers

iv) the anomeric configuration of the hydroxyl group on carbin 1 of each glucose unit.

The disaccharide with a bond between the 1 carbon of α - glucose and 4 - carbon of another α - glucose is called a MALTOSE. The bond is called α - 1, 4 glycosidic link. If however the left-hand sugar has been in the β form before linking then the compound would be a β-linked disaccharide. The compound of this sort which is comparable to maltose is called a CELLOBIOSE. Lactose, the sugar found in milk resembles cellobiose but the left-hand sugar is galactose instead of glucose. The structures of some common disaccharides are shown below:

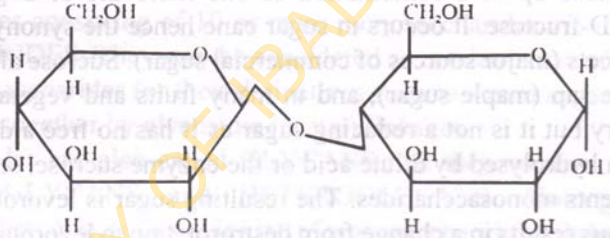
Common disaccharides

a) maltose



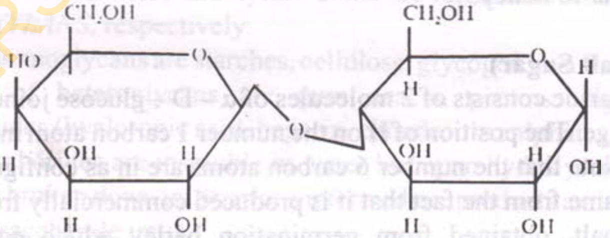
α – glucose α – glucose

b) cellubiose



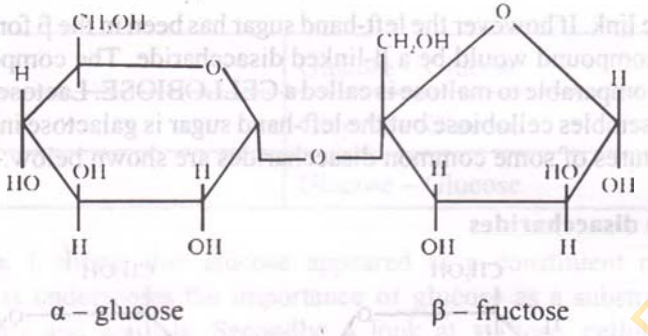
β – glucose α – glucose

c) Lactose



β – galactose α – glucose

d) Sucrose



Note: with the exception of sucrose, the ring of the right-hand glucose unit can open exposing a free aldehyde group and giving reducing properties to the sugars. Also, the dissaccharides are soluble in water, though to varying levels.

Short Notes on some Dissaccahrides

Sucrose (Cane Sugar)

Sucrose is made up of a combination of one molecule of D-glucose and one molecule of D-fructose. It occurs in sugar cane hence the synonym "cane sugar" and also in beets (major sources of commercial sugar). Sucrose also occurs in ripe fruits, in tree sap (maple sugar), and in many fruits and vegetables. Sucrose is dextrorotatory but it is not a reducing sugar as it has no free aldehyde or ketone group. When hydrolysed by dilute acid or the enzyme sucrose, sucrose splits into two constituents monosaccharides. The resulting sugar is levorotatory. Since the hydrolysis thus results in a change from destrorotation to levorotatum, the process is called INVERSION and the mixture of glucose and fructose is often termed INVERT SUGAR. Such a process is the way by which honey bees convert sucrose of plant nectar to honey.

Maltose (Malt Sugar)

This disaccharide consists of 2 molecules of α – D – glucose joined together in an α – 1, 4 linkage. The position of H on the number 1 carbon atom molecule (a) is the α position. Note that the number 6 carbon atoms are in as configuration. Maltose derives its name from the fact that it is produced commercially from starch by the action of malt, obtained from germination barley which contains a starch hydrolysing enzyme distaste.

Cellobiose

Consist of 2 molecules of B – D – glucose joined together in a β – 1, 4 linkage. This linkage is the fundamental one for the cellulose molecule and cannot be split by mammalian enzyme. It can be split, however, by microbial and fungal enzymes or acid. Cellobiose does not occur in free form in nature but only as a component of glucose polymers.

Lactose (Milk Sugar)

This is the sugar of milk and consists of one molecule of α – D – glucose and one molecule of β – D – galactose, joined in a linkage. This linkage can be separated by the enzyme lactase or by the addition of acid. It is a reducing sugar and is only one-sixth as sweet as sucrose. Lactose is of special interest in nutrition, because it makes up nearly half of the solids of milk and because it does not occur in nature except as a product of the mammary gland. Having discussed the mono-and disaccharides we shall now focus on the third and last class of carbohydrates — the polysaccharides.

III. Polysaccharides

The carbohydrates consisting of 10 or more monosaccharides are referred to as POLYSACCHARIDES. They may be considered as condensation of polymers in which the monosaccharides (or their derivatives such as amino sugars and uronic acids) are joined together by glycosidic (acetal) linkages.

Polysaccharides are also called GLYCANS and they consist of two types namely HOMOGLYCANS and HETEROGLYCANS. Homoglycans are polysaccharides that consist of a single kind of monosaccharide while heteroglycans consist of more than one kind of monosaccharide.

Polysaccharides consisting mainly of glucose are called *GLUCANS* while those consisting of fructose, mannose and xylose alone are referred to as *FRUCTANS, MANNANS* and *XYLANS*, respectively.

Examples of homoglycans are starches, cellulose, glycogen, insulin, chitin, etc. while examples of heteroglycans are gum acacia, pectins, alginic acids, mucopolysaccharides (hyaluronic acid, heparin, chondroitin sulphates). Generally speaking, polysaccharides are insoluble in water but upon hydrolysis by acids or enzymes, they are broken down into various intermediate products and finally their constituent monosaccharide units.

In this aspect of the course we shall be concerned with starch, cellulose and glycogen. Other polysaccharides will be discussed in future.

Starch

Starch is a storage carbohydrate found in plants. It consist of glucose units. it is therefore a homoglucan (remember our earlier discussion on homoglycans!). Starch consist of a mixture of 2 different types of molecules, amylose and amylopectin Amylose consists of a long chain of glucose units joined by α-1,4 linkages while amylopectin consists of a mixture of α 1, 4 links with occasional α 1, 6 branches (fig 3.). The branches occur after about 25 straight α 1, 4 bonds. Starches from different sources vary in the ratio of amylose and amylopectin, in the size of the individual molecules, in general amylopectin accounts for about 70% of starch.

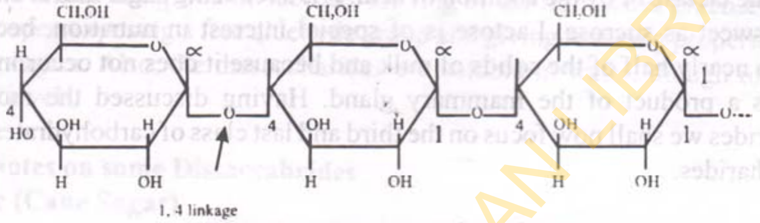


Fig. 3: *Structure of amylose*

The structure above is the glucose units of amylose linked in an unbranched chain. The amylose structure can therefore be considered as an expanded maltose structure with a free sugar group on one end.

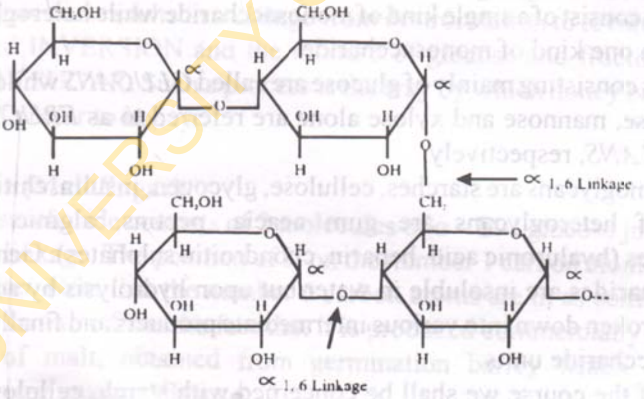


Fig. 4: *Structure of amylopectin*

Amylopectin also contains chains of glucose units like those of amylose, also has branches of these glucose chains linked through the 6 – OH of glucose in the manner as shown in Fig. 4.

The long chains of amylose roll themselves into a stable helix shape which is held in place by hydrogen bonding. The helix is a tube into which other molecules or atoms can fit. One example of this is the fact that iodine can fit inside the helix and form a blue coloured complex with amylose, a reaction which is often used to detect the presence of starch or iodine. The bluer the colour obtained, the more the amount of amylose component of the starch. Amylose is soluble in hot water while amylopectin is insoluble in hot water. Starches from different plants when viewed microscopically show difference in shapes and sizes (appearances). This property furnishes the basis for microscopic identification of different types of starches. Some starches show a high degree of hydrogen bonding and such starches are quite resistant to rupture. Tuber starch, such as found in the potato, is extremely resistant and must be cooked before being utilised by species such as pigs or chickens. Starch type in plants is genetically determined. However, starch modification techniques are available and have applications in the food industry. Dextrin is an intermediate resulting from the hydrolysis and digestion of starch as well as the action of heat on starch.

Cellulose

This is the most abundant substance in the plant kingdom and is a major structural component of plant cell walls. Cellulose is made up of polymerised glucose molecules ranging from 900 - 2,000 molecules. Cellulose is also a glucan. Chemically, cellulose is a polymer of β – 1, 4 – linked D – glucose units. As such, the six carbon atoms are in the trans position which results in cellulose being flat, band-like microfibril. Natural cotton is one of the purest forms of cellulose. Cellulose is not subject to attack by the digestive enzymes of man and other monogastrics, hence it is an important source of bulk in the diets. Contrarily, microbes in the rumen of ruminants can secrete cellulose enzyme which can degrade cellulose.

Cellulose is not soluble in water but soluble in ammonical solution of Cupric hydroxide, HCl acid solution of zinc chloride.

Glycogen

This is the storage form of carbohydrates in animals and fungal cells. Glycogen is deposited in the liver, which acts as a central energy storage organ in many animals. Glycogen is also abundant in muscle tissue, where it is more immediately available for energy release.

The structure of glycogen is of D-glucose combined with ∝ – 1, 4 linkage and an ∝ – 1, 6 cross linkage, very similar to that of amylopectin (component of starch moeity) except that the molecules are larger and the cross linkages move frequently (once every 15 or so straight bonds). Glycogen gives a red-brown, red, or at times, violet colour with iodine, and which yields D – glucose upon complete hydrolysis.

Summary

Carbohydrates are classified into 3 major groups namely; monosaccharides, oligosaccharides and polysaccharides, respectively. The monosaccharides are the simplest forms of sugars and make up oligosaccharides and the polysaccharides. The carbohydrates can be represented by chemical and structural formulae. The structural formulae are either represented in straight chain or in ring forms. This is specially represented by the hexoses (6 - carbon sugars).

The carbohydrates are source of energy for animal nutrition. The monosaccharides and oligosaccharides are efficiently metabolised by simple stomach animals. On the other hand ruminants contain microbes while secrete enzymes capable of degrading cellulose. Glycogen is a polysaccharide found in animal and fungal cells. Glycogen is a storage form of carbohydrate and readily utilized when there is deficiency of energy.

Post-Test

1a) What are monosaccharides, oligosaccharides and polysaccharides?

b) Using necessary chemical structures give 2 examples of the classes of carbohydrates listed in 1(a) above.

2. Write short notes on the following:
   a) Glycans
   b) Starch
   c) Cellulose

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LECTURE SEVEN

The Chemistry of Lipids

Introduction

Lipids are biological substances that are soluble in organic solvents. Apart from being structural components of biological membrane, they also play a major role in the nutrition of the animal. Just as carbohydrates can supply energy, lipids can also carry out this function.

In this chapter, we will focus on functions of lipids, their classification and the structures of some common lipids.

Objectives

Students will learn what lipids are, their functions and structures of some lipids.

Pre-Test

1a) What are lipids?
b) Discuss the importance of lipids in the animal.

2a) Name 3 unsaturated fatty acids.
b) Name 3 saturated fatty acids.
c) Give the chemical structures of the fatty acids mentioned in 2(a) and 2(b) above.

CONTENT

Definition of a lipid, functions of lipids, classes of lipids, naming of fatty acids.

Definition of Lipid

Lipids are *biological molecules* that are *soluble in organic solvents*. Lipids therefore include fats, oils, waxes, and related compounds. Occasionally, the term *lipoid* may be used in place of *lipid*. These two terms are synonymous and therefore can be used interchangeably.

Importance of Lipids

Lipids have the following biological functions:

i) Certain lipids, fats, serve as efficient reserves for storage energy. Such lipids are found in the adipose tissues.

ii) Fats serve as carriers for the fat soluble vitamins. The fat-soluble vitamins are, Vitamins A, D, E and K (A,D,E,K).

iii) Lipids constitute the major structural elements of membranes. When lipid is in combination with a protein the resulting substance is termed LIPOPROTEIN, i.e. *lipid-protein*.

vi) Fat serves as insulating material in the subcutaneous tissues around certain organs.

v) Cholesterol, an example of a lipid, is a major substance from which Vitamin D and sex hormones are synthesized.

Classification of Lipids

Bloor classified lipids as follows:

i) **Simple Lipids** — These are *esters of fatty acids* with various alcohols. Example of simple lipids include fats (esters of fatty acid with glycerol), waxes.

ii) **Compound Lipids** — These are esters of fatty acids but containing in addition, alcohol and a fatty acid. Examples of compound lipids include phospholipids, e.g. (glycerophospholipids), sphingophospholipids, cerebrosides (glycolipids) — compounds containing the fatty acids with carbohydrates, containing nitrogen but no phosphoric acid.

Other compound lipids include sulpholipids, aminolipids, lipoproteins.

iii) **Derived Lipids** — These are substances derived from the hydrolysis of simple lipids and compound lipids. The derived lipids include fatty acids, glycerol, steriods, alcohols in addition to glycerol and sterols, fatty aldehydes and ketone bodies. Because glycerides (acylglycerols), cholesterol and cholesteryl esters are unchanged they are also termed neutral lipids.

Fatty Acids

Fatty acids are a group of aliphatic carboxylic (- COOH) acids, which contains from 2 to 24 or more carbon atoms. Fatty acids are obtained from the hydrolysis of fats. However, fatty acids can also occur in natural fats and such fatty acids normally contain an even number of carbon atoms (i.e. from 2-carbon units) and are also striaght-chain derivatives (aliphatic).

Fatty acids can either be saturated or unsaturated. We shall elaborate on this shortly. Fatty acids can also be straight-chain or branched. However, the most abundant types of fatty acid are saturated and unsaturated straight-chain fatty acids. Before we get to discuss how fatty acids are named (nomenclature) let us first look at saturated and unsaturated fatty acids.

Saturated Fatty Acids

These are fatty acids that do not contain any unsaturated bonds (i.e. having single bonds). The general formular for the saturated fatty acid is $C_nH_{2n} + {}_1COOH$ – the first member of this group is acetic acid. Others will be discussed later.

Unsaturated Fatty Acids

These are fatty acids that contain one or more double bonds (unsaturated bonds). Unsaturated fatty acids with only one double bond are called MONOUNSATURATED fatty acids or MONOETHENOID ACIDS. Those with more than one double bonds are referred to as POLYUNSATURATED fatty acids (PHFA) or POLYETHENOID.

Naming of Fatty Acids (Nomenclature)

Genevan System

This is the most frequently used systematic nomenclature. This system is based on naming the fatty acid after the hydrocarbon with the same number of carbon atoms. In this case — oic is substituted for the final -e in the name of the hydrocarbon. This is illustrated with the examples below:

Butan/e becomes butan/oic acid
methane becomes methanoic acid

But for unsaturated fatty acid — enoic is added in place of -ioc.

Carbon atoms are numbered from the carbonyl carbon (i.e. carbon number 1). The next carbon atom after the carboxyl carbon (i.e. carbon 2) is also known as the ∝ – carbon (alpha carbon). Carbon atom number 3 is the β – carbon (Beta carbon) and end methyl carbon is known as w – carbon (omega carbon).

The second convention uses the number of carbon atoms between the methyl carbon and the nearest double bond and uses the n – (n minus) notation. This convention is particularly useful for identifying formulas of fatty acids derived from common precursor fatty acids as $\Delta^{9,12}$ (18, 2 or C18: 2n – 6).

It is conventional to indicate the position of the double bond by the following Δ^9, i.e. indicates a double bond between carbon atoms 9 and 10 of the fatty acid.

Methyl
Carbon

Carbonyl Carbon

$$^{4\omega}CH_3 - {}^{3\beta}CH_2 - {}^{2\alpha}CH - {}^{1}COOH$$

Monosaturated fatty acids ($C_nH_{2n} + 1COOH$)

Name	**Formular**	**Occurrence**
Acetic acid	CH_3COOH	Major end products of carbohydrate fermentation by rumen microbes
Propionic acid	C_2H_5COOH	Major end products of carbohydrate fermentation by rumen microbes
Butyric acid (Butarwic)	C_3H_7COOH	In certain fats in small amounts as butter. Fermentation in rumen
Caproic (Hexanoic)	$C_5H_{11}COOH$	In certain fats in small amounts as butter. Fermentation in rumer
Caprylic (Octanoic)	$C_7H_{15}COOH$	Butter
Capric (Decanoic)	$C_9H_{19}COOH$	Butter
Lauric (Dodecanvic)	$C_{11}H_{23}COOH$	Spermacetic, cinnamon, palm kernel, coconut oils
Myristic (Tetradecanoic)	$C_{13}H_{27}COOH$	Nutmeg, palm kernel, coconut oils
Palmitic (Hexadecanoic)	$C_{15}H_{31}COOH$	Common in all animal and plant fats
Stearic (Octadecanoic)	$C_{17}H_{35}COOH$	Common in all animal and plant fats
Arachidic (Eicosanoic acid)	$C_{19}H_{39}COOH$	Peanut (arachis) oil

Other higher members also occur in waxes.

A few branch-chain saturated fatty acids have also been isolated from both plant and animal sources. The long chain saturated fatty acids have lower rates of absorption than the shorter chain or the unsaturated fatty acids in both non-ruminants and the ruminants.

Monosaturated Fatty Acids

General formula $C_nH_{2n} - 1COOH$

Trivial Name	**Systematic Name**	**Shorthand**
Palmitoleic acid	$C_{15} - \Delta^9$ – hexadeconoic acid	Δ^9 C16 : 1
Oleic acid	$C_{15} - \Delta^9$ – octadecenoic acid	Δ^9 C18 : 1
Gondoic acid	$C_{15} - \Delta^{11}$ eicosenoic acid	Δ^{11} C20 : 1
Erucic acid	$C_{15} - \Delta^{13}$ docosanoic acid	Δ^{13} C22 : 1
Nervonic acid	$C_{15} - \Delta^{15}$ – tetrasenoic acid	Δ^{15} C24 : 1

Palmitoleic and oleic acids are more nutritional significance than other mentioned above.

Polyunsaturad Fatty Acids
2 double bonds
General formular
$C_nH_{2n} - 3COOH$ e.g. Linoleic acid (C18 : 2; 9, 12).

3 double bonds
General formular
$C_nH_{2n} - 5COOH$ e.g. Linolenic acid (C18 : 3; 9, 12, 15).

4 double bonds
General formular
$C_nH_{2n} - 7COOH$ e.g. Arachidonic acid (C20 : 4; 5, 8, 11, 14).

Linoleic acid	$C_{15} - \Delta^{9,12}$ – Octadecadienoic acid	$\Delta^{9,12}$ (C18 : 2)
γ Unoleic acid	$C_{15} - \Delta^{6,9,12}$ – Octadecatrienoic acid	$\Delta^{6,9,12}$ (C18 : 3)

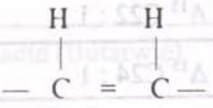
∝ – linolenic acid	$C_{15} - \Delta^{9,12,15}$ – octadecatrienoic acid	$\Delta^{9,12,15}$ (C18 : 3)
Arachidonic acid	$C_{15} - \Delta^{5,8,11,14}$ – eicosatetrempoc acid	$\Delta^{5,8,11,14}$(C20 : 4)

Linoleic, linolenic and arachidonic acids are called ESSENTIAL FATTY ACIDS because animals are unable to synthesis (de novo) by themselves – for this reason they must be included in the diets.

C_{15} and Trans Configurations

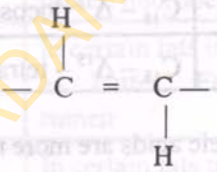
The polyunsaturated fatty acids also exhibit isomerism just as the carbohydrates do. But in the case of polyunsaturated fatty acids (PUFA) the isomerism depends on the orientation of atoms or groups around the axis of the double bonds. These two forms of isomerisms are described as C_{15} and trans configurations.

As a general rule, when the H atoms are found on the same sides of a double bond this is referred to as C_{15}, while if the H atoms are found on different sides of the double bond, this is referred to as trans. (Fig. X).



$$\overset{H}{\underset{}{—C}} = \overset{H}{C—}$$

C_{15}



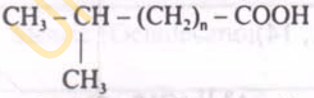
$$\overset{H}{—C} = \underset{H}{C—}$$

trans

The double bonds in most naturally occurring unsaturated fatty acids have the C_{15} – configuration, although fatty acids with trans double bonds are found in bacterial lipids. PUFAS with a combination of both C_{15} and trans double bonds are produced from C_{15} unsaturated fatty acids by chemical hydrogenation of vegetable oils, during the manufacture of margarines and during biohydrogenation of dietary PUFAS in rumen of ruminant animals.

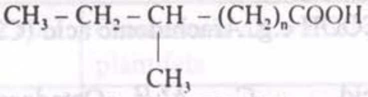
Branched Chain Fatty Acids

This term is normally reserved for fatty acids which contain one or more methyl (aid rarely ethyl) substituents along the carbon chain. Many microorganisms contain branch-chain fatty acids which are mainly iso and anteiso type.



$$CH_3 - \underset{CH_3}{CH} - (CH_2)_n - COOH$$

Iso-branched fatty acids



$$CH_3 - CH_2 - \underset{CH_3}{CH} - (CH_2)_nCOOH$$

Anteiso-branched fatty acids

Fig. Y

The fatty acid is Iso- type if the methyl (branch) is on the same carbon atom as the last methyl group of the fatty acid. It is anteiso - type if the methyl group (branch) is found on any carbon atom other than the one on which the last methyl group is attached (See Fig. Y).

These fatty acids are typical of most gram positive and sene gram-negative organisms. Trace qualities of iso and anteiso fatty acids (o.1 – 0.3%) are found in ruminant animal fat deposits. They arise as a result of the digestion and absorption of lipids from the rumen microorganisms as they pass through the small intestine. When certain unusual diets are provided, the proportion of branch-chain fatty acids in sheep and goat fat can be greatly increased.

Summary

Lipids are biological molecules that are soluble in organic solvents. Lipids play important role as sources of stored energy, structural components of biological membranes. Lipids are classified into three major groups namely; simple, compound and derived lipids.

Fatty acids are obtained when fats are hydrolysed and they can be foods or synthesized deinovo. Fatty acids are either saturated or unsaturated or short or, long or straight or branched-chained. The saturated fatty acids contain single bonds and examples are acetic, propionic, butyric, stearic, arachidic acids, etc. while the long chain polyunsaturated fatty acids (PUFAS) contain one or more double bonds. Examples of PUFAS are palmitoleic, oleic, linoleic, linolenic and arachidonic acids. The last three PUFAS (linoleic, linolenic and arachidonic acids) are classified as essential fatty acids because the body cannot synthesize enough hence they must be included in the diets.

Post-Test

1a) What are lipids?
b) Discuss the importance of lipids in livestock.

2a) What are saturated and unsaturated fatty acids?
b) Give the chemical structures of the fatty acids mentioned in 2(a) above.
3. Write short notes on the following:
   i) C_{15} and trans fatty acids
   ii) branch-chain fatty acids

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Introduction to Minerals in Animal Nutrition

Introduction

Minerals are indispensable part of a complete diet of farm animals. In this lecture, dietary essential minerals functions, factors affecting the requirements and sources will be discussed.

Objectives

At the end of this lecture, students should be able to:
1) Define essential and non-essential minerals.
2) List essential functions of minerals.
3) Enumerate factors that affect minerals requirements by the animals.
4) Identify the major sources of minerals.

Pre-Test

1) What are the essential minerals.
2) State the roles played by the minerals in the body of animals.
3) Enumerate factors that affect minerals requirements by the animals.

CONTENT

What are Essential Minerals

Essential minerals are those minerals recognised to carry out vital roles and which must be present in the feed. About forty minerals have been discovered to occur naturally in the tissues of animals and plants. Out of these forty, the dietary essential minerals are those that have been shown by research to have essential metabolic roles in the body. The proof that each of these elements is essential rests upon experiments with one or more species. If the experimental animals develop deficiency symptoms, the omitted mineral in the diet is considered to be essential to the animals diet. There are twenty-seven basic dietary essential minerals that have been recognised, it includes: calcium, phosphorous, magnesium, sodium, potassium, chlorine, sulphur, manganese, iron, copper, iodine, zinc, flourine, vanadium, cobalt, molybdenum, selenium, chromium, nickel, silicon and tin.

Fundamental Roles of Minerals

1) A very prominent function is in the formation of skeletal frame work. The skeletons of the vertebrates are made up of minerals especially Ca and P as constituents of bones and teeth, they give rigidity and strength to the skeletal structures.
2) Minerals are constituents of the soft tissues, example is in phospholipids that are present in protoplasm. They are components of body fluids, e.g. iron bond to protein in the blood.
3) The acidity and alkalinity of digestive juices are maintained by minerals and the acidity arises from hydrochloric acid which is formed from sodium chloride.
4) Many of their vital functions are due to an ionic inter-relationship which finds expression in the terms "antagonistic action" and "balanced solution". For example a certain balance between Ça, Na, and K in the fluid which bathes the heart muscle is essential for the normal relaxation and contraction which constitutes its beatings.
5) Minerals are important in the activation of many enzymes and hormones.
6) Mineral salts are sometimes fed to dairy and feedlot cattle beyond the established requirements because in their role as buffers, the salts have been reported to improve feed intake, milk production, milk composition and animal health. Mineral salts used as buffers control excess hydrogen ion concentration in the rumen, intestines, tissues and body fluids or increase the rate of passage of fluids from the rumen or both.

Factors Affecting Mineral Requirements

Many factors determines the utilization of minerals:

a) Inter-relationship among minerals or relationship between minerals and organic fractions may result in enhanced or decreased mineral utilization. Because of the many inter-relationships among minerals, almost any minerals, may influence directly or indirectly the utilization of any other mineral.
b) The actual amount of mineral in the diet may also influence utilization. For example if the diet contains more Ca than that required, the efficiency of absorption is usually decreased
c) The minerals status of the animal may also influence absorption. A magnesium deficient animals is more efficient in the absorption of magnesium better than animal with sufficient magnesium stores.
d) The form of the minerals is also an important determinant of utilization. Iron oxide is not available but ferrous sulphate can be readily utilized.

e) Many genetic-nutrition relationships have also been demonstrated. Examples of the extreme genetic effects are shown by one strain of mice that requires a high dietary level of Cu and by another strain of mice that requires a very high level of Mn. A strain of cattle that has a genetic defect in Zn metabolism has been identified. On the other hand, a strain of mice that is resistant to Zn depletion has been reported.

f) Many more subtle differences exists. The copper requirements of merino sheep is reported to be 1 to 2 ppm higher than that for the British breeds.

g) Changes in management practices may also influence the minerals requirement. For example, the Ca nutrition of growing pigs has been studied at many experiments stations but there is still disagreement as to the optimum dietary level.

Sources of Minerals

The mineral content of plants depends largely on the mineral content and pH of the soil in which the plants are grown. Many soils are deficient in specific minerals, and crops raised on these soils have same mineral deficiencies. Plants' Ca and P contents are especially important since animals need fairly large amounts of Ca and P. Other plants usually contain minute amounts of Ca or levels that are lower than animals need. Seeds are low in Ca but contain high level of P. Leaves contain higher levels of both Ca and P than stems. The main mineral in bone are Ca Phosphate and carbonate. Small quantities of Mg, Na, Sr, Pb, citrate, flouride hydroxide and sulphate are present in the bone.

Mineral Supplements

As mentioned earlier in our lecture, in certain parts of the world, the soils may be insufficient in one or more minerals that animals need and therefore, the plants grown in those soils are mineral deficient. However, for animals to survive in these areas, their rations must include minerals fortification. When selecting a mineral supplement one should consider its:-

1) Mineral composition.
2) Availability in the immediate environment.
3) Cost per unit of mineral compare to other supplements.

Summary
Mineral elements are solid crystalline, chemical elements that cannot be decomposed and synthesized by ordinary chemical reactions. They are present in both plants and animals to execute specific functions. The amount to be required by animals is largely determined by certain inherent factors.

Post-Test

1) Differentiate between essential and non essential minerals.
2) What are the functions of minerals to farm animals?
3) State the factors that determine the mineral requirements by the livestock.

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LECTURE NINE

Macro- and Micro-Minerals in Animal Nutrition

Introduction

In the last lecture, twenty-one mineral elements were listed and tagged "essential elements". In this lecture, the twenty-one elements will be grouped into macro (major) and micro (trace) minerals. Also, the specific functions of some macro and micro minerals shall be highlighted.

Objectives

At the end of this lecture, students should be able to define macro and micro minerals. In addition, you should be able to give some examples, functions and deficiency symptoms of macro and micro minerals.

Pre-Test

1. Differentiate between major and trace mineral
2. What are the functions of calcium, phosphorus, magnesium, sodium, sulfur and iron?
3. List the deficiency symptoms of Ca, P, Mg,Na, sand, Fe.

CONTENT

Macro-minerals

Macro mineral, also called major element are essential minerals that are required in large amount by the animals. These include calcium, phosphorus, magnesium, sodium, potassium sulfur and chlorine.

Micro-minerals

Micro minerals (trace elements) are those that animals need in small amounts but that are indispensable to animals productivity and health. Such minerals include manganese, iron, copper, Iodine, flourine, vanadium, cobalt, molybdenum, chromium, Tin, Nickel and silicon; some of these trace elements could be potentially toxic if used in large quantities.

Specific Functions and Deficiencies of Minerals

Calcium

Calcium is the most abundant mineral in the body of the animals with over 99% of it present in the bones and teeth. It is an important constituent of most living cells and tissue fluids, it functions in blood coagulation, bone formation, homostatic relations and as enzyme co-factors.

Calcium deficiency

a) Rickets: In young growing animals, bone growth is affected as sub normal calcification of bone occurs. Thus the joints become swollen, stiffness and lameness of the limb. Such deformations are seen in the chicken breasts, arched back in calves and bowed legs in humans.

b) Osteomalacia: This occurs in mature vertebrates. The bones become weak, porous and soft. They break readily hence fractures are common in farm animals and human suffering from osteomalacia. In pregnant sows, the fractured vertebrae may pinch the spinal cord leading to paralysis.

c) Osteoporocis: There is a decrease in the absolute amount bone in the skeleton. The rate of bone formation may be normal but increased bone resorption occur in attempt to maintain blood calcium.

Phosphorus

A part from the large amounts of phosphorus in the bones and teeth, a range of 20-25% of P in the body is found in the extracellular soft tissues. The major functions of P are:-

1. Needed for bone and teeth formation.
2. Carbohydrate metabolism as sugar phosphate, adenosine phosphates and creatine phosphate.
3. In lipid metabolism as it is essential for the formation of lecithin.
4. Formation of phospho lipid that are essential components of nerve tissues.
5. Formation of nucleoproteins of the chromatin material of genetic importance.
6. Regulate acid-base balance.

Phosphorus Deficiency

Rickets in young growing animals and ostcomalacia in the adult. In rickets due to phosphorus deficiency, reduction occurs in blood level phosphorus. Depraved appetite called "Pica" also occur in cattle. The animals eat woods, rags, bones, rocks. They have rough hair coat and become emaciated. Reproductive disorders, reduced growth and reduced milk production can also occur in cattle.

Magnesium

The skeleton contains 60% of the Mg found in the body. Magnesium functions in relation to enzyme is several ways.

a) Component of an enzyme. Metallo proteins contain inorganic elements. Arginase that breaks arginine into omithine and urea contains Mg as a component of its molecules.
b) Activator of Enzyme; for example, kinase and mutases that catalyse phosphorylation by ATP and molecular rearrangement respectively require magnesium.
c) Enzyme inactivator. In muscles, myosin ATP is activated by Ca but in activated by Mg contrast with actomyosin ATP.

Magnesium Deficiency

Magnesium deficiency can be due to low intake. However, trace elements studies show how absorption as low as 10-20% in some cases, from feeds and forages. Results are:-

1. Vasodilation with reduced blood pressure
2. Hyperirritability and
3. Tetany followed by death

"Grass staggers", "Grass tetany" and Magnesium tetany are used for Mg deficiency in adult ruminants.

Sodium

Sodium is supplied to animals mainly in the form of Nacl. Most of the feeds and forages are low in Na. However, plants that grow in alkaline soil have fair amounts. Two major functions of Na are:

a) Regulation of osmotic pressure
b) Maintenance of acid-base balance

Sodium Deficiency

1. There is reduction of growth
2. Reduced utilization of protein and energy
3. Lowered egg production in poultry
4. In laboratory animals, there is reproductive disturbances

Potassium

Potássium is found abundantly in plants and animals. It functions in the regulation of intracellular osmotic pressure, it regulates intracellular acid- base balance, stimulates muscular irritability like Na, and take part in the metabolism of proteins and carbohydrates. Potassium [k+] and sodium [Na+] in adrenal arterial - blood are important regulators of aldosterone secretion potassium is also important in the pyravic kinase reaction.

Potassium Deficiency

When hypo potassemia occurs, the general effects are muscular weakness, lethargy, anorexia, myocardial degenerative changes, pulmonary oedema, peripheral paralysis.

Chlorine

Supplied to animals mainly as Nacl like Na, Cl is present biologically in ionic form. The functions of chlorine include:

1. Regulation of osmotic pressure
2. Acid- base equilibrium
3. Chief anion of gastric juice that plays major roles in digestion and absorption of foods and feeds.

Deficiency of Chlorine

Animals deficient of chlorine exhibit decreased appetite, reduced growth rate, lowered milk production, feather picking and cannibalism in poultry. There is also heamoconcentration and retention of nitrogenous waste products.

Sulphur

Found mainly in organic form as components of proteins (cysteine, cystine and methionine). In the hormone insulin in glutathione, thiamine, biotin and lipoic acid. In ruminants traces of inorganic S tends to improve the utilization of urea as a Nitrogen sources. Large inorganic S intake is injurious to these animals. The rumen microflora produce H_2S which is absorbed and then causes disturbances.

Manganese

Found in fairly constant amounts in plants and animals. Manganese functions as the activator of many enzymes systems. The major ones are (a) pyravate carbonylase which contains the minerals and Mn functions in the trans carboxylation phase of enzymatic reactions (b) In the synthesis of micopoly saccharine of cartilage, Mn act as a catalyst in the glucosamine-serine linkages. Others are bone phosphatase, muscle adenosine - tri-phoshate, peptidases and choline esterases. Mn is needed for normal reproduction in mammals.

Deficiency of Manganese

In deficiency states, the sexual maturity of the female is delayed, irregular ovulation and weak young ones are produced. In males, testicular degeneration leads to sterility. In cattle there is poor growth, leg disorders, poor fertility and frequent abortion. In pigs, the deficiency symptoms are poor bone growth, shortening of leg bones, enlarged hocks muscular weakness, increase back fat and irregular oestrus. In poultry, slipped tendon, malformation of bones of leg, reduced egg shell thickness and reduced hatcherbility.

Iron

Iron is present in small amount, 70% of which is found in the haemoglobin, the remainder is found mainly in the liver, spleen, bone-marrow, plasma myoglobin and various oxidation reduction enzymes. Iron functions as respiration pigments (haemoglobin, myoglobin) and in enzyme systems.

Deficiency of Iron

More than half of iron in the body is found in haemoglobin and the formation of pigment is affected by Fe deficiency. Anaemia is the result. Iron deficiency is not common in ruminants. Iron deficiency in sheep and cattle causes depraved appetite (pica) similar to phosphorus deficiency. It is characterised by diarrhoea, loss of appetite and anaemia.

Copper

Copper like Fe is needed for haemoglobin formation. Like Fe, Cu is stored in the liver but smaller amounts are stored in the brain, bone marrow, spleen, heart and kidneys. Like Fe, Cu may also be components of enzymes systems especially oxidation reduction systems. However, Cu also function in the neurological systems.

Deficiency of Copper

Anaemia results from low intake of either Cu or Fe. Other results are depressed growth bone disorders, depigmentation of hair and wool, demyelination of spinal cord and lesion in the brain. There is muscular inco-ordination of gastrointestinal disturbances and diarrhoea..

Young lambs tends to be more susceptible to neonatal ataxia or sway back. Falling disease in grazing cattle is an atrophy of the myocardium with replacement fibrosis. The animal staggers, falls and sudden death tends to ensue due to acute heart failure.

Peat scours in cattle is due to low Cu and high molybdenum. In cattle Cu deficiency delays or depresses ocstrus thereby decreasing fertility. In poultry, hatchability is reduced and embryonic abnormalities may occur.

Copper functions as a growth promotant as it has antibacterial properties against a broad spectrum of organism..

Zinc

Very small amounts of zinc are needed by animals and many plants contain zinc adequately. The major role of Zn is as component of the enzyme carbonic anhydrase. It is also present in metallo enzymes like pancreatic carboxy-peptidase, alkaline phosphatase, various dehydrogenase as well as tryptophan desmolase. Zn is also a cofactor in enzymes like originase enolase, peptidases, carnosinase and oxaloacetic decarboxy lase.

Deficiency of Zn

The deficiency of Zn results in reduced appetite, retarded growth, gross lesions in the epithelial tissues hence poor reproductive organ development. In pigs, there is skin lesions on the legs and belly. In poultry, there is poor feathering. In ruminants, there is disorder of the hair coats and low milk production.

Summary

Minerals although nutritionally required in smaller amounts are essential for maintenance and production purposes by the livestock. However the major and trace minerals are needed by the body in large and small amount respectively. Generally, deficiencies of most minerals are shown by a reduced appetite and production, slow growth and occasionally death.

Post-Test

1 Differentiate between major and trace minerals.
2. What are functions of calcium and phospherus, magnesium sulfur and iron to livestock.
3. List the deficiency symptoms of Ca, P, Mg, Na, S and Fe.

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LECTURE TEN

The Vitamins

Introduction

The vitamins are part of a complete diet although needed in only minute amounts but essential and which deficiency could spell a doom for farm animals. Although the discovery of the vitamins dates from the beginning of the twentieth century, the association of certain diseases with dietary deficiencies had been recognised much earlier. The administration of cod-liver oil for example, in preventing rickets has long been appreciated. It was also discovered by the end of nineteenth century that beri-beri, a disease caused by vitamin B-complex could be cured by giving brown rice grain rather than polished rice.

Objective

At the end of this lecture, students should be able to define and classify vitamins with examples. They should also be able to state functions of the specific vitamins and list their deficiency symptoms.

Pre-Test

1) What are vitamins?
2) Classify vitamins with specific examples.
3) What are the functions and deficiency symptoms of vitamins A,D,E,K and B-complex?

CONTENT

What are Vitamins?

Vitamins are pure chemical compounds that livestocks require in very small amounts for growth, maintenance, reproduction and lactation. They differ from other nutrients in that they do not build body tissues but are components of certain enzyme and hormone systems and thus are essential for the normal life processes. Some vitamins are metabolic essential for animals but are not considered as dietary essential because sufficient amounts are synthesized in the body to meet requirements. For easy understanding and comprehension, vitamins are naturally divided into two groups of fat and water soluble.

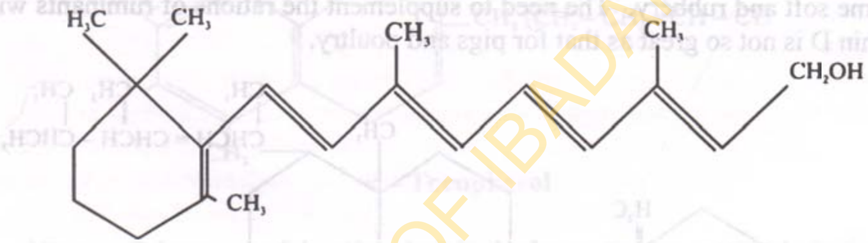
Fat-Soluble Vitamins

Fat soluble vitamins may be stored where fat is deposited and the storage increases with intake. The fat-soluble vitamins regulate metabolism of structural unit. The fat-soluble vitamins include vitamins A,D,E and K.

Vitamin A

Vitamin A, known chemically as retinol, is an unsaturated monohydric alcohol with the following structural formula:

There is no animal that does not require a dietary source of vitamin A. Liver is a good source of vitamin A. Other animal sources are cod-liver oil, egg yolk and milk fat. Plants are said not to contain the actual vitamin A but its precusor, carotene. Carotene is a provitamin A because the body can transform it into the active vitamin. The carotenoids present in the food get changed to vitamin A within the intestinal wall. Excess vitamin A is stored in the liver.



Vitamin A affects vision and a necessity for normal bone development. It helps to keep epithelial tissues healthy and functional. The main deficiency disorders of vitamin A in animals include:

a) Loss of appetite, inhibited growth, increased susceptibility to infection and death.
b) The skin is dry, scaly and poor hair production.
c) Night blindness
d Respiratory tract, that is extensive keratinisation of lining cells, loss of ciliary epithelium.
e) Digestive tract (Keratinisation of mucous membrane, loss of gland activities, poor absorption, infections).

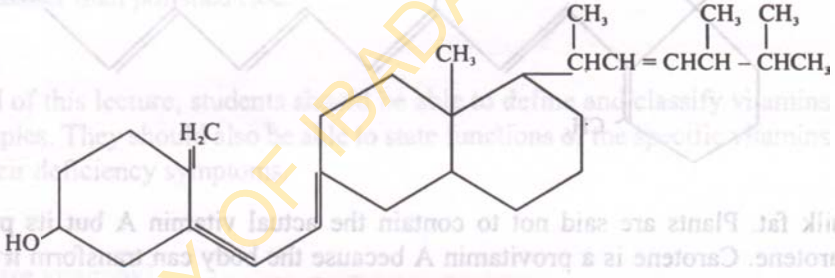
f) Urinary tract (Metaplasia of epithelium and increased tendency to stone formation)

g) Bones (There is overgrowth of porous bone tissue resulting in nerve compression).

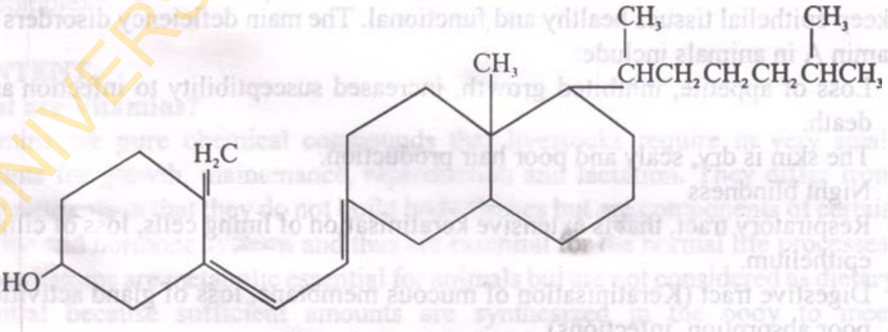
h) Male, severe degeneration of ovary, decline in egg production by poultry and decreased fertility. Infection of genital tract.

Vitamin D

There are many forms of vitamin D, but the two outstanding forms are ergocalciferol (D_2) and cholecalciferol (D_3). Incorporation of Ca and P into bone matrix is dependent on adequate supply of vitamin D. The vitamin stimulates absorption of Ca and P from the intestinal lumen. It also stimulates the reabsorption of Ca+P in the renal tubules. If vitamin D is not present, rickets develop or the bones demineralize. Osteomalacia due to vitamin D deficiency is not common in farm animals. In poultry, deficiency of vitamin D causes the bones and beak to become soft and rubbery. The need to supplement the rations of ruminants with vitamin D is not so great as that for pigs and poultry.



Vitamin D_2 (ergocalciferol)

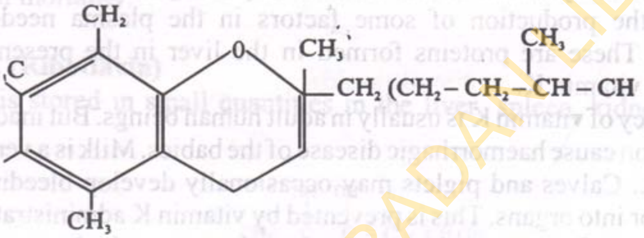


Vitamin D_3 (cholecalciferol)

Many fish oils, especially cod-liver oil and sun cured legume hays are good sources of vitamin D. Growing plants have no vitamin D, but vitamin D_2 is formed by the irradiation of plant ergosterol by the sun's rays after the plant is cut. Animals kept outside the pen receive enough vitamin D_3. The ultraviolet rays convert a precusor into D_3 to meet the animals needs, so the sun is a valuable vitamin source in the tropics.

Vitamin E

There are eight known forms of vitamin E that exist in nature, which can be grouped into ∝, β, Y and δ-tocopherols. Out of these, α-tocopherol is the most biologically active and most widely occurring everywhere.

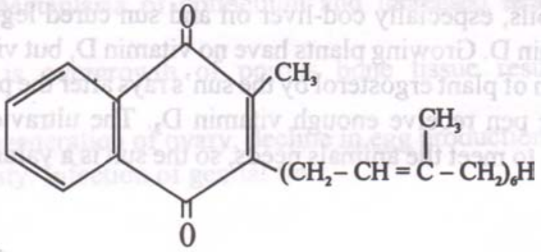


∝ – Tocopherol

Vitamin E is a powerful antioxidant in the lining tissues, particularly for lips. It protects other nutrients from oxidative destruction. Vitamin E is essential for reproduction in several species. Testicular degeneration has been reported in vitamin E-deficient pigs and rabbits. The vitamin can prevent and cure "stiff-lamb" disease, which is characterized by stiffness and dystrophic lesions. Chronic vitamin E deficiency has been noted to produce, in rabbits, lambs, poultry and cattle, electrocardiogram changes which are considered to reflect heart muscle injury. Vitamin E is abundant in whole cereal grains, in the germ, and in by-products that contain the germ. Green forages are excellent sources. Since vitamin E deteriorates easily, rancid feeds usually have none.

Vitamin K

A number of compounds posses vitamin K activity, but the two outstanding compounds naturally occurring are vitamins K_1 (Phylloquinone), found in green plants, and K_2 (menaquinone), which is a product of bacterial growth. Menaquinone is the metabolically active form of the vitamin.



Menaquinone

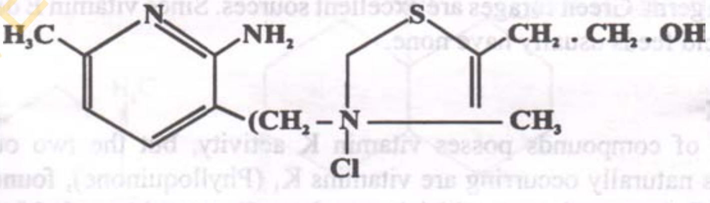
Vitamin K is usually present in adequate amounts in dietary sources. There is also an intestinal synthesis of the vitamin. Physiologically, vitamin K is usually needed for the production of some factors in the plasma needed for blood coagulation. These are proteins formed in the liver in the presence of minute quantities of vitamin K.

Deficiency of vitamin K is usually in adult human beings. But inadequate intake and production cause haemorrhagic disease of the babies. Milk is a very poor source of vitamin K. Calves and piglets may occasionally develop bleeding at mucous membranes or into organs. This is prevented by vitamin K administration. In chicks and growers, a deficiency results in general weakness, rough plumage, paleness and icteric colouration of the comb, wattles and eyelids as a result of anaemia.

Water Soluble Vitamins

The water soluble vitamins are concerned with reactions dealing with energy transfer. Water soluble vitamins must be consumed regularly in the ration and in adequate amounts. The water-soluble vitamins include B-complex and vitamin C.

Vitamin B_1 (Thiamin)



Thiamin chloride

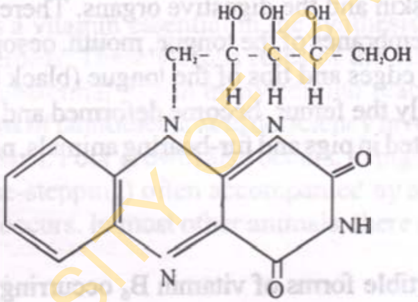
Thiamin is widely distributed in foods. Brewers' yeast is a rich source. The vitamin is concentrated in the germ of cereal grain and is also present in the aleurone layer. Other sources are beans, peas and green leafy crops. Animal products rich in thiamin include egg yolk, liver, kidney and pork muscle.

Vitamin B_1 is present in almost all living tissues thus reflecting its significance in carbohydrate metabolism. The deficiency symptoms of vitamin B_1 include:

1) General condition in terms of loss of appetite, decreased growth, weight loss, general weakness, lowered temperature.
2) Nervous system (paralysis).
3) Slowing of pulse and respiration, fatty degeneration of heart muscle fibre.
4) Diarrhoea and intestinal atomy.
5) Inhibition of testicular development, ovarian atrophy, premature birth and high neonatal mortality.

Vitamin B_2 (Riboflavin)

Riboflavin is stored in small quantities in the liver, spleen, kidney and cardiac muscle.



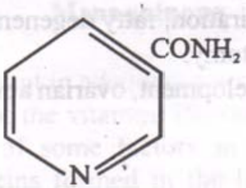
Riboflavin

The vitamin B_2 occurs in all biological materials. It functions as flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD) as components of the flavin enzymes catalyzing hydrogen transfer. The flavin enzymes of the respiratory chain participate in the metabolism of carbohydrates, amino acids and fatty acids.

Typical deficiency symptoms of riboflavin are seen in the skin and mucous membranes with inflamation at the interphase between the skin and mucous membrane at several body apertures e.g inflamation of the mouth and nasal mucous membranes, fissures at the corners of the mouth and eye lids. Atrophy, oedema and inflamation of the mucous membranes of the digestive tract result in difficulties in swallowing, disorders in food absorption and diarrhoea in pigs and chicken. In laying birds hatchability of incubated eggs is first reduced, followed by fall in egg production.

Nicotinamide

This vitamin is the amide derivative of nicotinic acid and it is the form in which it functions in the body. Nicotinamide is a stable vitamin and is not easily destroyed by heat, acids, alkalis, or by oxidation.

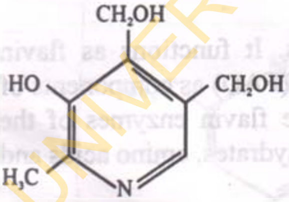


Nicotinamide

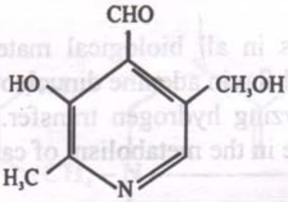
Deficiency symptoms of nicotinamide are shown and characterised by severe metabolic disorders in the skin and the digestive organs. There is inflamation and ulceration of the mucous membranes of the tongue, mouth, oesophagus. Also, there is dark pigmentation of the edges and tips of the tongue (black tongue disease). In poultry, the bones, especially the femur, become deformed and curved. The blood and vascular system is affected in pigs and fur-bearing animals, normocytic anaemia develops.

Vitamin B$_6$

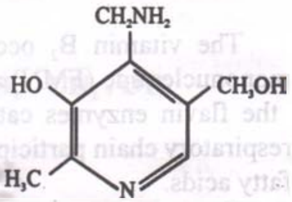
There are three interconvertible forms of vitamin B$_6$ occurring is the body which include pyridoxine, pyridoxal and pyridoxamine.



Pyridoxine



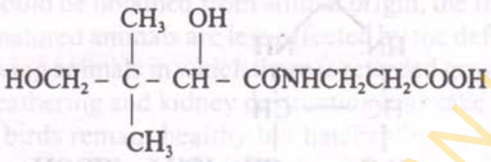
Pyridoxal



Pyridoxamine

The vitamin is widely distributed, and yeast, liver, milk, pulses and cereal grains are rich sources. Vitamin B_6 functions in several enzyme systems concerned in protein metabolism. Its deficiency symptoms include poor appetite, slow growth and poor feed utilization by pigs and poultry. In rabbits, there are flakes formed on the skin of the ears, nose and paws. In pigs, the coat looks rough and brown. The calf suffers loss of hair and poor feathering in poultry. There is also a fall in poultry egg production, lowered hatchability, high embryonic mortality in second week.

Pantothenic acid
Pantothenic acid is ubiquitously available in nature. Some good sources of the vitamin are egg yolk, liver, groundnuts, peas, yeast, molasses and cereal grains.



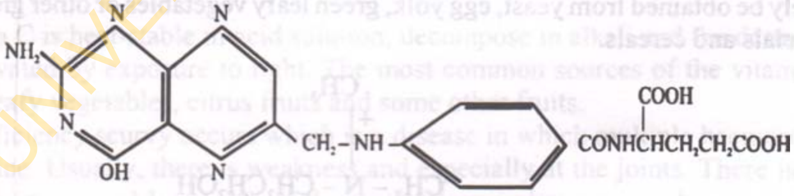
$$HOCH_2-\underset{CH_3}{\overset{CH_3}{C}}-\overset{OH}{CH}-CONHCH_2CH_2COOH$$

Pantothenic acid

Pantothenic acid is a vitamin essential in the synthesis and catabolism of fats and the synthesis of steroids. These various roles of the vitamin serve to illustrate the fact that it plays an essential role in many cellular reactions.

The main lesions of pantothenic acid deficiency involve the nervous system, the adrenal cortex and skin. Poor growth also occurs. In pigs a high stepping action with the hind legs (goose-stepping) often accompanied by a scabby dermatities around the eyes and snout occurs. In most other animals, there is alopecia after loss of hair pigment.

Folacin
Folacin is a derivative of folic acid denoted by the following formula:



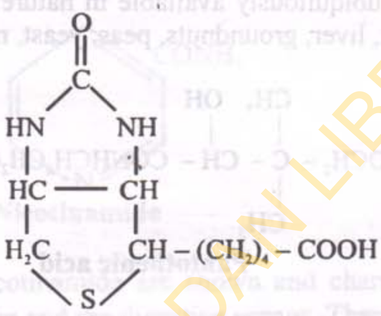
Folic Acid

Folacin is an antianaemia factor. It is widely distributed in nature; green leafy materials, cereals, extracted oilseed meals and animal protein meals are rich sources.

The vitamin plays a basic biochemical role in the transfer of simple-carbon units in various reactions. There is increased demands for folic acid during pregnancy as the foetus withdraws the vitamin from the mother. Hence folic acid, proteins and iron are considered important for the expectant mothers.

Biotin

The structure of biotin is written below.

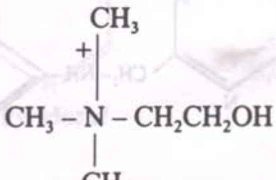


All cells contain some biotin but larger concentration in the liver and kidneys. Biochemically, biotin participates in carboxylation reaction by causing biological "activation" of carbon-dioxide. Biotin is widely distributed in foods; liver, yeast, milk and vegetables are rich sources.

In poultry, the deficiency of biotin results in impaired growth, dry and brittle feathers, dermatitis and perosin. Eggs from biotin deficient birds have poor hatchability and embryonic malformations. In pigs, mucous membranes are affected resulting in furry tongue.

Choline

Illustrated below is the structure of our next vitamin known as choline. Choline can largely be obtained from yeast, egg yolk, green leafy vegetables or other green leafy materials and cereals.



$$CH_3-\overset{\overset{CH_3}{+|}}{\underset{\underset{CH_3}{|}}{N}}-CH_2CH_2OH$$

Choline is a vital structural component of animal body tissues. It is a constituent of lecithins which play an essential function in cellular structure and activity. It prevents the accumulation of fat in the liver.

Deficiency symptom is indicated by retarded growth and accumulation of fat in the liver, especially in pigs and chicks. Choline is also concerned with the prevention of perosis or slipped tendon in chicks.

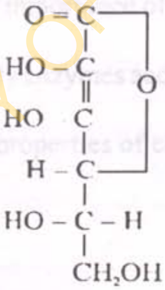
Vitamin B_{12}

Another name so called by this vitamin is cyanocobalamin and it is the most complex of all vitamins. In this lecture, you will not be bothered about its structure. The vitamin is believed to be synthesised exclusively by micro-organisms and its presence in foods is thought to be mainly of microbial origin.

Vitamin B_{12} could be obtained from animal origin, the liver being a principally rich source. The matured animals are less affected by the deficiency of vitamin B_{12}, unlike young growing animals in which there is retarded growth and high mortality. In poultry, poor feathering and kidney destruction may take place. Despite the fact that the deficient birds remain healthy but hatchability is badly affected. In pigs, there is uncoordination of the hind legs.

Vitamin C

Vitamin C is more popular among other vitamins. Chemically, it is otherwise called L-ascorbic acid and posses the following simple formula:



Vitamin C is heat-stable in acid solution, decompose in alkali and the destruction is motivated by exposure to light. The most common sources of the vitamin are green leafy vegetables, citrus fruits and some other fruits.

Deficiency scurvy occurs which is a disease in which multiple haemorrhages take place. Usually, there is weakness and especially at the joints. There is pain, bleeding gums and loosening of the teeth. Haemorrhages may also occur in the conjuctivae, retina or even cerebrum.

Summary

Vitamins, which the two main classes are fat soluble and water soluble are chemically unrelated organic compounds. The requirement by the animals is very low but the deficiency in these animals could result in poor growth, poor egg and milk production, loss of appetite high mortality and susceptibility to diseases.

Post-Test

1. What are vitamins?
2. Classify vitamins with specific examples.
3. What are the functions and deficiency symptoms of vitamins A,D,E and K?

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LECTURE ELEVEN

The Nature, Properties and Classification of Enzymes

Introduction

Enzymes were discovered by the German Chemist, Edward Buchner towards the end of the nineteenth century. The word enzyme which literally means 'in yeast' serves as a collective name for the many hundred of compounds that have been shown to have a catalytic action on specific biochemical reactions in living cells.

Enzymes are molecules which catalyse biochemical reactions by acting on their substrates and converting them into products. Enzymes are referred to as reaction specific catalysts because, in contrast to inorganic (non protein) catalysts, each enzyme catalyses a small number of reactions, sometimes only one.

Objectives

1. To understand the nature and importance of enzymes in biochemcial reactions of living organisms.
2. To be able to name and classify enzymes according to the type of reactions they catalyse.
3. To have a knowledge of the properties of enzymes.

Pre-Test

1. What are catalysts?
2. What is catalysis?
3. What are the importance of enzymes?
4. Give four examples of enzymes of metabolic reactions.

CONTENT

- The importance of enzymes
- The classification of enzymes
- The properties of enzymes
- Co-enzymes

The Importance of Enzymes

Most biochemical reactions of living cells would occur very slowly were it not for catalysis by enzymes. Although, enzymes undergo physical change during biochemical reactions, they revert to their original state after the completion of reactions.

Enzymes not only speed up reactions in the living cells, they also control them, ensuring that metabolism proceeds in an orderly fashion.

The Classification of Enzymes

Generally, an enzyme is named by attaching the suffix (-ase) to the name of the substrate on which it acts e.g. proteases act on proteins, maltose catalyses maltose and lipase acts on lipid.

Enzymes are grouped according to the type of reaction they catalyse. The groups are:

1. **Transferases: Enzymes in this group play an important part in energy production and other metabolic processes in cells. The reactions they participate in involve the transfer of atoms or group of atoms from one molecule to another, e.g a hydrogen atom, phosphate group, amino group, aldehyde or kentone residues etc. Examples of enzymes classified under this group are phosphorylase, hexokinase, cholineacyttransferase etc.**

2. **Oxidoreductases:** These include the enzymes also known either as dehydrogenases (enzymes that specifically catalyse the removal of hydrogen atom from a substrate e.g. alcohol dehydrogenase) or as oxidases (enzymes that catalyse the addition of oxygen to hydrogen e.g. cytochrome oxidase) oxidoreductases are involved in the final steps in respiration.

3. **Hydrolases:** These are enzymes catalysing hydrolysis of ester, ether, peptide, glycogyl etc. E.g. B-galactosidase, pepsin, Chymotrypsin etc.

4. **Lyases:** These are enzymes that catalyse the removal of groups from substrate by mechanism different from hydrolysis. Examples are aldolase and fumarase.

5. **Isomerases:** These are enzymes catalysing the transfer of atoms from one part of a molecule to another, e.g alanine racemase, triosephosphate isomerase.

6. **Ligases:** These include enzymes catalysing the linking together of two

compounds and the breaking of a pyrophosphate bond in ATP (Adenosine triphosphate) or a similar compound e.g glutamine synthetase and succinic thiokinase.

The Properties of Enzymes

1. Enzymes generally work very rapidly. This speed of action makes enzymes much more efficient than inorganic catalysts.
2. Enzymes are not destroyed by the reactions they catalyse and so are reversible. However, they differ from inorganic catalysts in that they cannot be used indefinitely. Enzymes are very unstable and are readily inactivated by heat, acids etc.
3. Enzymes work in either direction i.e forward and backward. Reactions catalysed by an enzyme will move in these forward and backward direction until an equilibrium between substrate and product is reached.
4. Enzymes are inactivated by excessive heat. This is because they are proteins and at high temperatures, proteins are denatured.
5. Enzymes are sensitive to PH. Every enzyme has its own range of PH in which it functions most efficiently, but most enzymes in the cells function best at or a round neutral.
6. Enzymes are action specific. An enzymes will catalyse only one, or a type of reaction.

Co-enzymes

Many enzymes catalyse chemical reactions only in the presence of a specific non protein organic molecule called the co-enzyme. In this type of reaction, it is only when both the enzyme and the co-enzyme are present, will catalysis occurs. Chemical reactions that require the participation of co-enzymes are oxidoreductive, group transferring and isomerizative in nature. Also, reactions resulting in the formation of covalent bonds require the participation of co-enzymes. Chemical reactions including hydrolytic reactions catalysed by the enzymes of the digestive tract, are not known to require co-enzymes. An important co-enzyme is Nicotinamide Adenine Dinucleotide (NAD) which works in conjunction with dehydrogenase enzymes.

Summary

Enzymes are molecules which catalyse biochemcial reactions by acting on their substrates and converting them into products. The main function of enzymes is to speed up reactions in the living cells. They also control this reactions, ensuring that metabolism proceeds in an orderly fashion. An enzyme is named by attaching the suffix (-ase) to the name of the substrate on which it acts. Enzymes are classified according to the type of reaction they catalyse. The groups are Transferases, Oxidoreductases, hydrolases, Iyases, Isomerases, and ligases. Some of the properties of enzymes are; their speed of action, limitation to their use in living cells, inactivation by excessive heat, sensitivity to PH, and reaction specificity. Many enzymes catalyse chemical reactions only in the presence of specific non protein organic molecule called the co-enzyme. These reactions are oxidoreductive, group transfering and isomerizative in nature.

Post-Test

1. What are the factors affecting the rate of enzyme catalysed reactions.
2. Classify enzymes according to their functions in biochemcial reactions in living cells.
3. What is a co-enzymes?

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LECTURE TWELVE

Enzyme, It's Mode of Action and Inhibition

Introduction

An enzyme-catalysed reaction is usually characterized by a very large increase in the rate (on the order of 10^6 to 10^{12}). The enzyme molecule is capable of selectively catalysing certain reactants, called substrates, while discriminating against other molecules. Enzymes generally work very rapidly and are not destroyed by the reactions they catalyse, and so are reversible. There are compounds in living cells that decrease the rate of an enzyme-catalysed reaction. These are known as inhibitors.

Objectives

1. To have an insight on how enzymes work.
2. To understand the reason for the high degree of specificity shown by enzymes.
3. To have a knowledge of the importance of enzyme inhibition.

Pre-Test

1. What do you understand by chemical equilibrium?
2. What are the factors affecting the rate of chemical reactions?
3. What do you understand by feed back mechanism?
4. Explain reversible and irreversible reactions.

CONTENT

- How enzymes work
- Enzyme Inhibition

How Enzymes Work

When an enzyme-controlled reaction takes place, the enzyme and substrate molecules combine with each other. The substrate molecules collide with the usually much larger enzyme molecules and then combine with them. Figure 1 below shows an increase in the rate of reaction as presented by curve A with an increasing concentration of substrate, the enzyme concentration being kept constant.

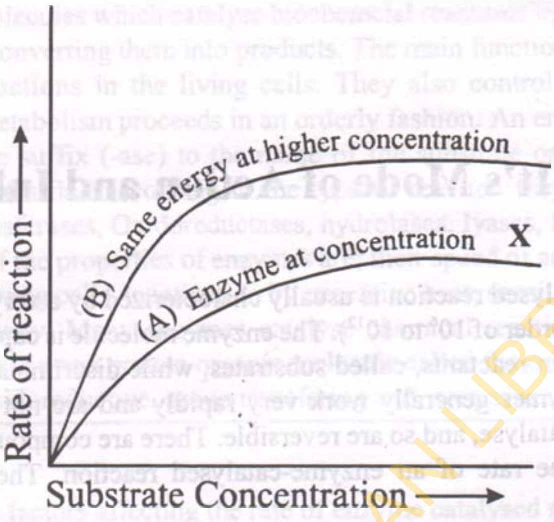

Fig. 1: The Effect of Substrate Concentration on the rate of an enzyme-controlled reaction

The curve levels up at a point when the substrate concentration reaches a certain level, and the system has become saturated. This phenomenon indicates that, the more substrate molecules there are, the greater the chances of substrate and enzyme molecules colliding in the right way. Therefore the only way to increase the rate of reaction is to increase the enzyme concentration to give a new picture as presented by curve B.

In an enzyme controlled reaction, the substrate molecules combine with the enzyme to form an enzyme-substrate complex. The substrate molecules with their various bonds held in relation to each other by the enzyme react together to form an enzyme-product complex, which then splits into the enzyme and product. The enzyme, unchanged by the reaction is re-usable.

$$E + S \rightleftarrows ES \rightleftarrows P + E$$

Where E and S are enzyme and substrate respectively; ES, an enzyme-substrate complex; and P, the product formed.

The high degree of specificity shown by enzymes leads to the suggestion of the lock and-key hypothesis, where the substrate can be represented by the padlock and enzyme by the key. It is suggested that each enzyme molecule has a precise place on its surface, known as the active site, to which the substrate molecules become attached. The active site of an enzyme molecule has a distinctive configuration into which only certain specific substrate molecules will fit. The shape of this active site, and the positions of the different chemical groups within it, ensure that only those substrate molecules with a complementary structure will combine with the enzyme (see Fig. 2). The lock-and-key hypothesis also explains why enzymes are inactivated by excessive heat. Since enzymes are proteins, denaturation by heat brings about changes in shape, and prevent the substrate molecules fitting into the site.

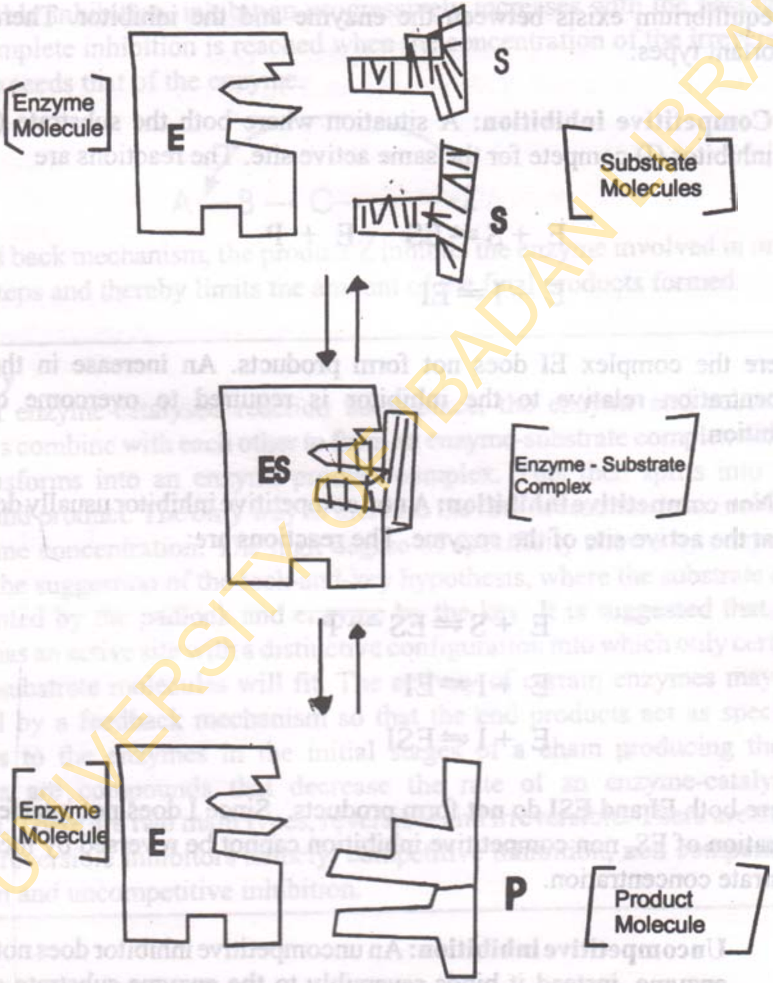

Fig. 2: The lock-and-key hypothesis explaining enzyme action

Enzyme Inhibition

Inhibitors are compounds that decrease the rate of an enzyme-catalysed reaction. The activity of certain enzymes may be regulated by a feedback mechanism so that the end products act as specific inhibitors to the enzymes in the initial stages of a chain producing them. There are two types of enzyme inhibitions; reversible and irreversible.

Reversible Inhibition

An equilibrium exists between the enzyme and the inhibitor. There are three important types:

i) **Competitive inhibition:** A situation where both the substrate (S) and the inhibitor (I) compete for the same active site. The reactions are

$$E + S \rightleftharpoons ES \rightarrow E + P$$

$$E + I \rightleftharpoons EI$$

Where the complex EI does not form products. An increase in the substrate concentration relative to the inhibitor is required to overcome competitive inhibition.

ii) **Non competitive inhibition:** A non competitive inhibitor usually does not bind at the active site of the enzyme. The reactions are:

$$E + S \rightleftharpoons ES \rightarrow P$$

$$E + I \rightleftharpoons EI$$

$$E + I \rightleftharpoons ESI$$

Where both EI and ESI do not form products. Since I does not interfere with the formation of ES, non competitive inhibition cannot be reversed by increasing the substrate concentration.

iii) **Uncompetitive inhibition:** An uncompetitive inhibitor does not bind to the enzyme, instead it binds reversibly to the enzyme-substrate complex to yield an inactive ESI complex. The reactions are:

$$E + S \rightleftharpoons ES \rightarrow P$$

$$ES + I \rightleftharpoons ESI$$

where, the ESI does not form a product. Again, since I does not interfere with the formation of ES, uncompetitive inhibition cannot be reversed by increasing the substrate concentration.

Irreversible Inhibition

In irreversible inhibition, inhibition progressively increases with the passage of time. A complete inhibition is reached when the concentration of the irreversible inhibitor exceeds that of the enzyme.

$$\begin{tikzcd}A \arrow[r] & B \arrow[r] & C \arrow[r] & \cdots \arrow[r] & Z \arrow[lll, bend right]\end{tikzcd}$$

In this feed back mechanism, the product Z inhibits the enzyme involved in one of the early steps and thereby limits the amount of the final products formed.

Summary

When an enzyme-catalysed reaction takes place, the enzyme and substrate molecules combine with each other to form an enzyme-substrate complex which later transforms into an enzyme-product complex. This then splits into the enzyme and product. The only way to increase the rate of reaction is to increase the enzyme concentration. The high degree of specificity shown by enzymes leads to the suggestion of the lock-and-key hypothesis, where the substrate can be presented by the padlock and enzyme by the key. It is suggested that, an enzyme has an active site with a distinctive configuration into which only certain specific substrate molecules will fit. The activity of certain enzymes may be regulated by a feedback mechanism so that the end products act as specific inhibitors to the enzymes in the initial stages of a chain producing them. Inhibitors are compounds that decrease the rate of an enzyme-catalysed reactions. There are two main types, reversible and irreversible. There are three types of reversible inhibitors namely, competitive inhibition, non competitive inhibition and uncompetitive inhibition.

Post-Tests

1. Describe an enzyme-catalysed reaction.
2. Explain the concept of enzyme inhibition.
3. Describe with illustration, the lock-and-key hypothesis.

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LECTURE THIRTEEN

The Nature, Classification and Functions of Hormones

Introduction

Hormones are organic compounds produced in one part of the body, from which they are transported to other parts where they produce a response. Hormones are secreted by endocrine organs directly into the blood stream. They are carried by the blood around the body bringing responses in various organs referred to as target organs.

Hormones have influence on one another and are integrated into a highly coordinated system called the endocrine system. This system provides means of communication within the body of an organism. The message transmitted from an endocrine organ to a target organ takes the form of a chemical substance conveyed through the blood system.

Objectives

1. To understand the nature and importance of hormones in the physiological process of the living organisms.
2. To have a knowledge of the endocrine.system; the glands and their secretions.
3. To understand the functions of hormones in the animal body.

Pre-Test

1. What are hormones?
2. What are the importance of hormones?
3. Give examples of organs in the body where hormones are produced.

CONTENT

- The endocrine system.
- Hormones secreted by the endocrine glands and their functions.

The Endocrine System

The endocrine system consists of glands widely separated from one another and having no direct anatomical relationship. The glands are commonly referred to as ductless glands because their secretions pass directly from their cells into the blood stream, and not through a duct or a canal. The endocrine system consists of the following glands;

i) Pituitary gland
ii) Thyroid gland
iii) Parathyroid glands
iv) Adrenal glands
v) The Islets of Langerhans in the pancreas
vi) Pineal gland
vii) Ovaries in the female
viii) Testes in the male

Hormones Secreted by the Endocrine Glands and their Functions

Pituitary gland

The pituitary gland has three distinct parts;

i) the anterior lobe
ii) the middle lobe and
iii) the posterior lobe

The anterior lobe: The hormones produced by the anterior pituitary is responsible for the stimulation of the production hormones by other endocrine glands or the growth of the body as a whole. The hormones secreted by the anterior lobe and their functions are:

a) ***Growth hormone or somatotrophic hormone:*** stimulates growth directly and in association with other hormones. The hormone affects the growth in the length of the long bones and promotes protein anabolism. It also influences the absorption of calcium from from the bowel and in conversion of glycogen to glucose.

b) ***Thyrotrophic hormone or Thyroid Stimulating Hormone (TSH):*** controls the growth and activity of the thyroid gland. It also influences the uptake of iodine, for the synthesis of the hormone thyroxine and tri iodothyronine by the thyroid gland.

c) ***Adrenocorticotrophic Hormone (ACTH):*** stimulates the adrenal gland to produce its hormones.

d) ***Lactogenic Hormone (Prolactin):*** in conjunction with other hormones stimulates the mammary glands to secrete milk.

e) ***Gonado trophic Hormones (Sex hormones):*** The anterior lobe secretes three gonado trophic hormones;

   i) The Follicle Stimulating Hormone (FSH); which stimulates the development and maturation of the ovarian follicle in female animals and promotes the production of spormatozoa (the male germcells) in the male.

   ii) The Luteinising Hormone (LH); promotes the final maturation of the ovarian follicle and influences the discharge of mature ovum (ovulation). It is also responsible for the formation of the **Corpus luteum** (yellow body) which secretes an ovarian hormone known as progesterone.

   iii) The Interstitial Cell Stimulating Hormone (ICSH); stimulates the interstitial cells in the testes to secrete the hormone testostorone.

f) ***The Posterior Lobe:*** The secretion of the posterior lobe is known as pituitrin and it consists of two hormones, oxytocin (pitocin) and vasopressin (Antidiuretic Hormone — ADH).

   i) Oxytocin: this hormone promotes contraction of the uterine muscle and the release of milk during lactation.

   ii) Vasopressin: increases the permeability to water of the cells in the kidney and is responsible for the contraction of the involuntary muscle in the walls of the intestine, gall bladder, urinary bladder and blood vessels.

g) ***The middle lobe:*** This is the smallest part of the pituitary gland. It is believed that it secretes a hormone that is associated with the growth and development of melanocytes which give the skin its colour.

The Thyroid Gland

The thyroid gland secretes three hormones; thyroxine, tri iodothyronine and calcitonin. The functions of thyroxine and tri iodothyronine are;

i) The control of utilization of oxygen in the body thus influencing basal metabolic rate.
ii) Stimulation of the absorption of carbohydrate from small intestine.
iii) Influence of heat production during catabolism of nutrients materials in the cells.
iv) Association with nerve stability.
v) Responsibility for the maintenance of healthy skin and hair and
vi) For normal mental and physical development.

The function of calcitorum is to reduce the blood level of calcium by inhibiting the re-absorption of calcium from bones.

The Parathyroid Glands

The parathyroid glands secrete the hormone parathormone, to maintain the blood concentration of calcium within normal limits. The hormone stimulates the mobilisation of calcium from the bones.

The Adrenal Glands

The adrenal cortex produces a considerable number of different substances which have been classified into three groups; glucocorticoids, mineralocorticoids and sex hormones.

Glucocorticoids: Contains cortisol and corticosterone for regulation of carbohydrate metabolism.

Mineralocorticoids: Aldosterone is the name given to the main mineralocorticoid and its functions are associated with the maintenance of the electrolyte balance in the body.

The Sex Hormones: These are testosterone, oestrogen and progesterone. The adrenal gland is the sources of sex hormones until the testes and ovaries mature at puberty. The secretion of the sex hormones by the adrenal cortex is controlled y ACTH and not by gonado troping which stimulate the testes and ovaries. The functions of the sex hormones include; the influence of development and maintenance of secondary characteristics in both male and female, and to increase the deposition of protein in muscles and reduce the excretion of nitrogen, especially in the male.

The adrenal medulla produces catecholamines called adrenalin and noradrenalin which function in; dilation of the coronary arteries, thus increasing the blood supply to the heart muscle; dilation of the bronchi, allowing greater amount of air to enter the lungs at each inspiration; dilation of the pupil of the eye; constriction of blood vessels to the skin, thus raising the blood pressure and reducing the secretion of saliva and other digestive juices.

The Islets of Langerhans

The Islets of Langerhans have two main types of cell. These are the ∝ cells which produce a hormone called glucagen and β cells which produce insulin. Both hormones influence the level of glucose in blood, each balancing the effects of the other. Glucagen tends to raise the blood glucose level while insulin reduces it.

Functions of Glucagen

1. Raises blood glucose level.
2. Converts liver glycogen to glucose.
3. Promotes gluconeogenesis.

Functions of Insulin

1. Reduces blood glucose level.
2. Enables glucose to enter cells.
3. Promotes conversion of glucose to glycogen.
4. Promotes storage of fat.
5. Promotes synthesis of protein.

An insufficiency of insulin in the body leads to the development of a disease condition known as diabetes mellitus, which is characterised by disturbances in both glucose and fat metabolism.

The Pineal Gland

The functions of the pineal gland are yet not clear. It may be associated with the development of gonads by influencing the release of gonado-trophic hormones from the anterior pituitary.

Ovaries in the Female

The hormones oestrogen and progesterone are produced in the ovaries. The production of oestrogen is stimulated by the gonado-trophin, Follicle Stimulating Hormone (FSH), where progesterone is produced from **Corpus luteum** under the influence of the Luteinising Hormone (LH).

Functions of Oestrogen

1. Influences ovulation
2. Stimulates the proliferation of the endometrium in preparation for the reception of fertilized ovum.

Functions of Progesterone

1. Prepares the endometrium to assist the passage of spermatozoa.
2. Influences the preparation of the uterine walls for the development of the fertilized ovum or ova.

Testes in the Male

The Luteinising Hormone, or as it is called in the male, the Interstitial Cell Stimulating Hormone from the anterior lobe of the pituitary gland stimulates the testes to produce the hormone testosterone. The function of testosterone is to influence the development of the body to sexual maturity.

Summary

Hormones are organic compounds produced in one part of the body, from which they are transported to other parts where the produce a response. Hormones have influence on one another and are integrated into a highly cor-ordinated system called the endocrine system. The endocrine system consists of glands commonly referred to as ductless glands because their secretions pass directly from their cells into the blood stream, and not through a duct. Hormones produced by the anterior pituitary is responsible for the stimulation of the production of hormones by other endocrine glands or the growth of the body as a whole. The thyroid gland, parathyroid glands, adrenal glands and the Islet of langerhans secrete hormones whose main functions are to influence the metabolic process. The hormones of the gonads i.e. the ovaries in the female and testes in the male are associated with the development of the body to sexual maturity and the reproductive process.

Post-Tests

1. Describe the endocrine system.
2. Give two examples of hormones that have direct influence on metabolism and in what ways?
3. Explain briefly the functions of hormones produced by the gonads.

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LECTURE FOURTEEN

Organisation and Control of Endocrine Systems

Introduction

At the physiological level of organization in the endocrine system, the control units are cells. Hormones act to change the activities of cells or the number of responsible cells. The activity of the entire endocrine system is a highly integrated network. Hence, a disturbance such as a removal or malfunction of one gland, leads to changes in the functions of many other glands and a change in the activities of other hormones upon target cells (cells responsive to hormones).

Objectives

i) To have an insight into hormonal action.
ii) Understanding the mechanism of hormonal control.

Pre-Test

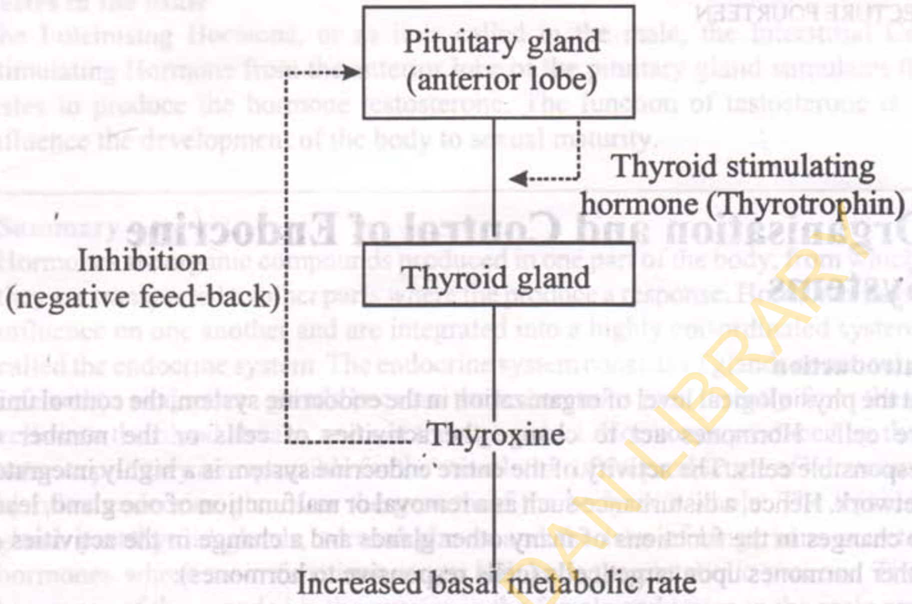
i) What is a negative feed-back mechanism'?
ii) Describe the following;
  a) hormonogen
  b) tropic hormones and
  c) target organs

CONTENT

- Hormone action.
- Hormonal control mechanisms.

Hormone Action

The principle of endocrine action using the thyroid gland as an example.



The thyroid gland secretes thyroxine which is a complex organic compound containing iodine. Thyroxine is responsible for controlling the basal metabolic rate and is therefore important in growth regulation. The release of thyroxine into the blood stream is triggered by a hormone secreted by the anterior lobe of the pituitary gland. This hormone is called thyroid stimulating hormone or thyrotrophic hormone. The production of this hormone is regulated by thyroxine itself. A slight excess in the level of thyroxine in the blood stream acts on the pituitary to secrete less thyrotrophic hormone and this in turn reduces the activity of the thyroid gland leading to the reduction in the production of thyroxine. This reduction of thyroxine in the blood stream removes the inhibiting influence on the pituitary so that more thyrotrophic hormone will be produced again. This example illustrates the principles of hormone action and this is referred to as negative feed-back mechanism.

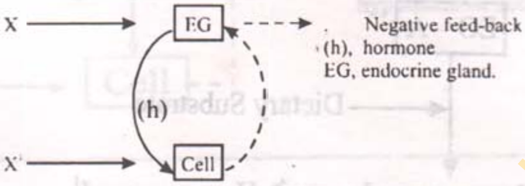
Hormonal Control Mechanisms

Various types of endocrine control systems have been recognized. Some of these are:

1. The simplest appears to be a system in which the hormone acts on specific cells, thereby promoting a change in the controlled variable in the extracellular

fluid, which in turn regulates the output of hormone by the gland (fig. 1). This negative feed-back system can be changed by endocrine and neural action exerted either upon the gland itself or upon the hormonally responsive effector cells. Systems of this type appear to operate in the case of insuline, parathyroid hormone (PTH) and aldosterone. An important feature of this type of system is the absence of direct hypothalamic or pituitary control.

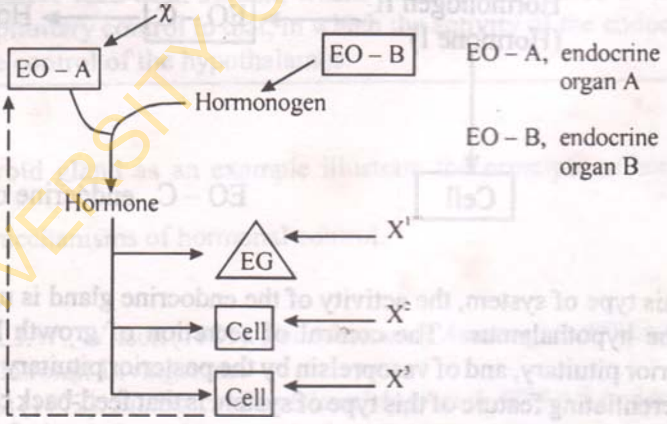
Fig. 1:



X and X^1, represents other factors operating independently of feed-back loop and influencing respectively, the activity of EG and cell

2. A hormonogen (a hormone precursor) is secreted into the blood stream by one organ, which is acted upon in the blood by an enzyme from another organ and is converted to a tropic hormone, which stimulates the production of a hormone by another organ. The hormone then acts on a target organ stimulating a response which leads to a decrease in enzyme production.

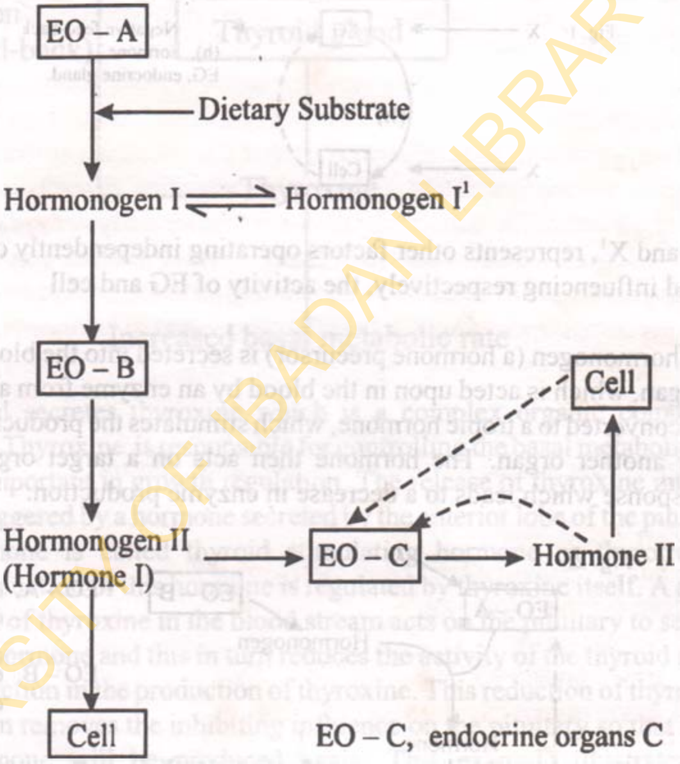
Fig. 2:



An example is angiostensonogen (hormonogen) converted into angiostensin, then into aldosterone (hormone).

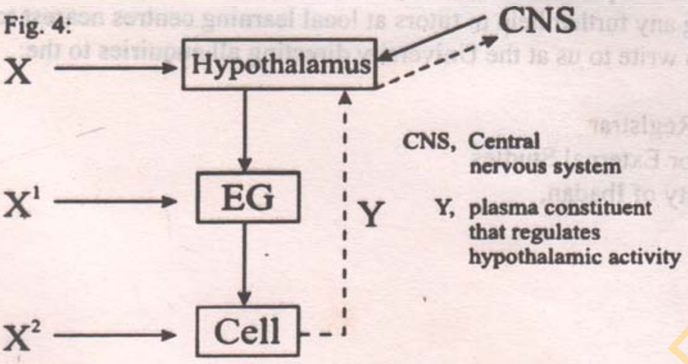
3. In this case, the hormonal precursor hormonogen can be derived from the diet or synthesized within the organism. It goes through successive transformations in several additional organs before becoming a biologically active substance. An example is the conversion of cholecalciferol to 25 - hydroxy - and 1, 25 - dyhydroxy cholecalciferol.

Fig. 3:



4. In this type of system, the activity of the endocrine gland is under the control of the hypothalamus. The control of secretion of growth hormone by the anterior pituitary, and of vasoprelsin by the posterior pituitary are examples. A differentiating feature of this type of system is that feed-back control is exerted not on the endocrine gland directly, but upon hypothalamic function, which in turn regulates gland function. The feed-back effector appears to be one or more plasma constituents.

Fig. 4:



Summary

Hormones act to change the activities of cells or the number of responsive cells. The activity of the entire endocrine system is highly integrated such that a disturbance from one gland leads to changes in the functions of many other glands and changes in the activities of hormones. the basic mechanism of hormonal action is referred to a negative feed-back and this is well demonstrated in the release of thyroxine into the blood stream by the thyroid stimulating hormone, whereby the regulation of this release is effected by thyroxine itself. This example illustrates the basic principle of hormone action. Several mechanisms of hormonal control have been described, from the simplest such as occurred in a negative feed-back system, where there is an absence of direct hypothalamic or pituitary control to that, in which the activity of the endocrine gland is under the control of the hypothalamus.

Post-Tests

1. Using the thyroid gland as an example illustrate the principle of hormone action.
2. Describe two mechanisms of hormonal control.

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