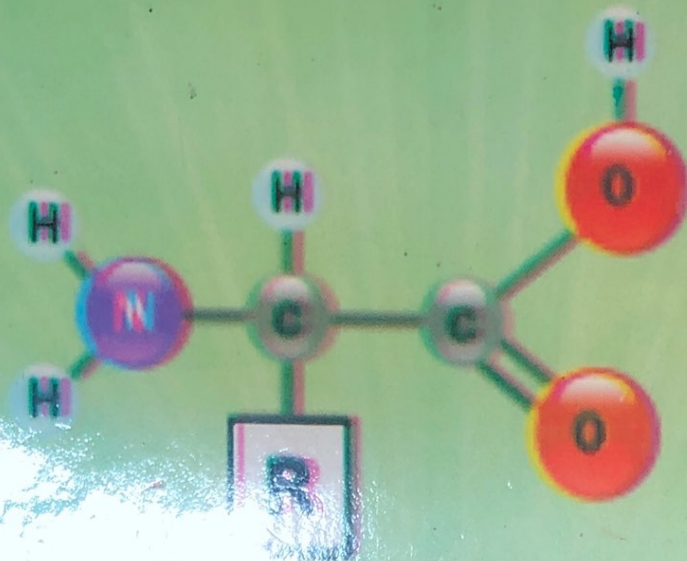




Animal Nutrition Basics

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ANIMAL NUTRITION BASICS

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DEDICATED

To an erudite professor of Animal Nutritional Biochemistry,
an astute education administrator and a generous
philanthropist,

OLUWAFEM OLAIYA BALOGUN

-for exemplifying Discipline, Honour and Empathy

PREFACE

Animal Nutrition Basics is aimed at providing students of animal production or related disciplines with the basic knowledge of nutrition required to maintain optimum health and productivity in poultry birds and livestock. The book gives due recognition to the inextricable interactions of the subjects of **nutrition, biochemistry and physiology**.

The book was divided into 16 units for ease of comprehension. The early part of the book, **Units 2-9** discussed the basic biochemical molecules in animal feeds and feeding. Physiology of feed digestion in animals was examined in **Unit 10** while the remaining units of the book explained how feed nutrients are utilized for cellular functions.

The authors are always receptive to comments and criticisms that are intended for quality enhancement.

ACKNOWLEDGEMENT

Teachers and academic mentors of the like of Professor O. O. Balogun, with whom the authors had the privilege of interactions and through whom the gift of DIAMOND in the form of knowledge was received, are all appreciated and thanked.

The regular challenging class room engagements with students of animal production have helped to keep the DIAMOND polished and lustrous. The students are also appreciated.

Several unknown authors who shared their knowledge in media that would be difficult for individual acknowledgement, further added value to the treasured DIAMOND. They are also appreciated.

Thanks also due to friends and professional colleagues who have helped - through positive criticisms, comments and encouragements - to protect the DIAMOND from depreciating in value.

*And the only true source of Help is
the Exalted in Power, the Wise.*

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Unit 1

The Science of Nutrition

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Nutrition

Nutrition is the science that seeks to interpret the relationship of food to the functioning of the living organisms. Nutrition is deals with the supply of energy substrates and nutrients to an animal's body. In its scope, nutrition studies;

- cultivation, preservation, and preparation of feeds
- intake of feed
- liberation of nutrients
- elimination of wastes
- synthesis of substances that are essential for maintenance, growth and reproduction

The primary aim in the study of animal nutrition is to protect structural and functional integrity of the animal tissues, and thereby maintain optimum growth, health, production and reproduction in the animal. The achievement of the aim is through the supply to the individual animal, a diet that is palatable, non toxic and which contains the required nutrients in adequate amounts, in the right proportion and in a form that is easy to assimilate by the body.

While exploring the scope of nutrition, the individual would be able to find appropriate answers to these and related questions;

- What are the physical and chemical natures of the animal's feed?
- How do animals consume, digest, metabolize, and store nutrients?
- How are the animal nourished through the feed they consumed?

- What is the influence of feed/feedstuff on the health of an animal?
- How do feed nutrients affect production and products quality in an animal?
- What factors influence the animal's eating behavior?
- What factors regulate the supply of feeds in the animal micro- or macro- environment?
- What factors influence the safety of feeds to the animal?

Chemical Composition of the Animal Body

Plants and animals contain chemical substances which are derived from the food they eat. Plants derive food from simple inorganic materials present in the air (CO_2) and soil (water, inorganic elements) while animals' food composed largely of plants and plants products

An animal feed is an edible material that is capable of being digested to release nutrients which are absorbed and assimilated for cellular functions. Nutrients are chemical substances in feeds that are required for normal functioning and development of the animal body. Gross composition of a typical animal feed/feedstuff is Dry Matter and Water. The six main groups of feed-nutrients are:

- Water
- Carbohydrates
- Lipids (including fats and oils)
- Proteins
- Vitamins
- Minerals

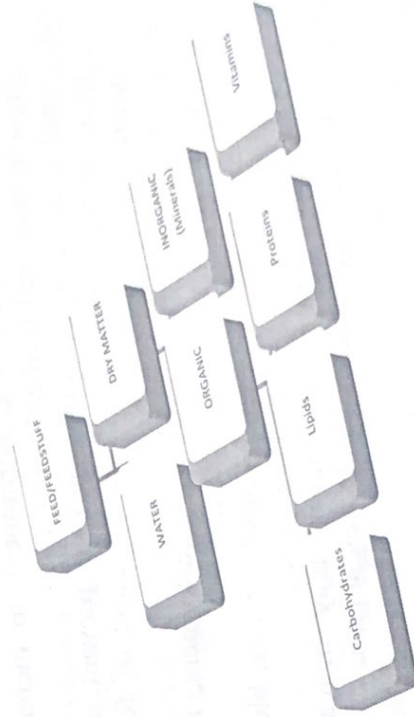


Figure 1: Composition of Feed/Feedstuff

A Ration or A Diet

A ration is the feed an animal receives over a 24-hour period. Feedstuffs that make up rations are selected based on the individual animal feed preference and requirement for nutrients, availability and relative cost.

Ration with all the nutrients an animal required in the right proportions are described as balanced rations. A diet on the other hand is the usual feed and drink of the animal. In other to improve on the feeding quality, certain substances known as feed additives are included in the composition of a ration or diet. Feed additives are substances added to animal feeds for;

- growth acceleration
- increased feed efficiency
- increased production of animal products,

- improved health condition

Feed additives may be classified on the basis of the purposes for which they are used which may be as;

- Growth promoters (e.g. hormones), to increase growth rates and feed efficiency
- Antibiotics (e.g. coccidiostats), to prevent and treat disease conditions. Another class of feed additives
- Anthelmintics, also known as dewormers, are used to control worm infestation.

Some of the other roles for feed additives are, as; bloat controller, anti-stress and pH level regulators, Antibiotics when used at low levels may increase efficiency of feed utilization and body weight gain.

Unit 2

Water in Animal Nutrition

Essentiality of Water

Water is the most essential nutrient – it is by far, the most critical nutrient required by a living organism. An adequate, clean water supply to animals is important for;

- proper balance of body fluids, regulation of nerve impulses and body temperature,
- muscle contractions
- nutrient transport, and excretion of waste products

An animal may be able to live for weeks or months without other nutrients, but it will die within days if deprived of water. Unfortunately, water is often not considered while formulating livestock rations.

The water content of an animal's body varies with species, age and physical environment. Water usually represents between 71 and 73% of fat-free body weight on the average. In young animals water may account for between 75 and 80 % of the body mass. The percentage water body water content declines gradually with advancing age to about 50 %, in adult animals.

Water Intake in Animals

Water intake varies considerably; it is often dependent upon physiological state of the animal and the environment. Average intake (liter/day) for different livestock species are:

- 38-110 (dairy cattle)
- 66 (beef cattle)
- 11-19 (pig)

- 4-15 (sheep & goat)
- 0.2-0.4 (chicken)
- The three major sources of water to an Animal are;
- Foods water – free water in the feed/feedstuff
- Metabolic water
- Drinking water

A variable but significant amount of water can be made available to animals through the feed they consume

- 9-13 % (common forages and grains)
- 65-75 % (Silages)
- Fresh Pasture (75-80 %)
- Common forages and grains contain 9-13% water available to animal
- 3 % (concentrates)
- above 90 % (root tubers & liquid foods)

Quiz Time

Calculate the water content in 40 kg fresh pasture sample which is 25% DM

Water which is chemically bound and released during metabolic processes is referred to as Metabolic Water. It is the water produced from various metabolic reactions in the body cells. Oxidation of H-containing nutrients in metabolism for instance, yields some molecules of water. Metabolic water varies with the type of nutrients in the diet. Carbohydrates release 0.6 gH₂O/gram nutrient, protein produce 0.4 g H₂O/gram nutrient while fats can yield about 1.0 g H₂O/gram nutrient. Some desert animals are able to derive the entire water requirements from free and metabolic water. An example is the

kangaroo rat that does not drink at all throughout a lifetime and may not know what to do with water if offered.

Loss of Water in an Animal

The primary routes of eliminating water from an animal's body are through the;

- Kidney as urine,
- Gastro-intestinal tract, GIT as faeces,
- Lung with CO₂ in expired air,
- Skin as sweat.
- milk production

Loss of water through urine increases when feed consumption increases or when ration contains high protein, mineral salts or fiber levels. Water losses through feces vary with species and feed moisture content. Cattle usually lose more water than sheep which reabsorbs more water in large intestine to produce dryer feces. Cattle on fresh pasture will lose more water than while in feedlot consuming hay and grain ration.

Loss of Water through respiration (CO₂ + H₂O) or skin surfaces (sweat) can be significant. In ruminants respiration is the primary route of heat loss. Excessive water loss in conditions of profuse sweating, diarrhea and prolonged vomiting may cause dehydration & loss of electrolytes.

Factors Affecting Loss of Water from an Animal's Body

Factors influencing the loss of water in animals include;

- Heat Load – in all animal species, water loss increases as heat load increases. At 40 degrees Fahrenheit, a 450 kg cow will lose 0.42 kg H₂O/hr; at 70 degrees Fahrenheit it will lose 0.63 kg H₂O/hr.
- Physical Exercise - Loss of water increases as intensity of physical exercise increases
- Milk Production- Loss of water through lactation increases with amount of milk produced. A cow producing 45 kg of milk is losing about 40 kg of water. The water lost must be replaced to meet the cow's metabolic requirements. Restriction of water intake is the fastest way to stop lactation in all animals.
- Fleece Production - Loss of water in sheep increases as fleece length increases
- Feed Composition - Protein rich diet increases rate of water loss as there would be an increased demand for water to eliminate nitrogenous waste products. In addition, proteins produce less metabolic water to the animal than carbohydrates or lipids. The water of oxidation (g/100 g nutrient) are 40 for protein, 56 for carbohydrates and 107 for lipids
- Physical Environment - Water loss is increased in a warm environment due to an increase in evaporative losses from the lung and skin

Functions of Water in Animals

- Water is essential for life - Life of a living cell depends upon contact with an aqueous environment. Plants or animals will succumb to water deprivation sooner than to starvation
- Water maintains the structure of bio-molecules such as proteins in the body.
- Water lubricates and cushion various parts of the body e.g. joints around spinal cord/brain; fetus.
- Water aids in the regulation of temperature – makes it easier to maintain body temp within narrow range. Water has high specific heat; it is able to absorb a lot of heat energy before temperature begins to rise. Loss of water through evaporation removes a lot of heat energy from body as a result of a high heat of vaporization of water
- Water is a carrier of metabolic nutrients and wastes. Water transports fluids and semi-solid ingesta through the Gastro-intestinal tract. It serves as a vehicle for the transport of absorbed nutrients across the body cells and carries metabolic wastes from excretory organs to the points of discharge.
- Water is a solvent for many chemical substances in the body. It provides a medium for chemical reactions in the body and sometimes takes part in the reactions

Regulation of Animal Body Temperature by Water

Water is able to regulate body temperature through of its properties; A high specific heat (conductivity) enables water to distribute heat evenly in the animal body. The latent heat of vaporization is also high which allows water to remove excessive heat produced by metabolic reactions, through vaporization

High specific heat together with high latent heat of vaporization prevents any drastic change in body temperature. Resulting from these two properties, water requires more heat to change from liquid to vapour or from liquid to solid than many other substances. Thus, body temperature would be kept fairly constant irrespective of changes in environmental temperature. The temperature regulatory function of water is very important to animals as chemical reactions in the body takes place within a narrow range of temperature

Water also has a peculiar Freezing Properties as a decrease in environmental temperature causes an increase in volume and a decrease in density of water. This is in contrast to many other liquids. Coldest water is usually at the surface while warm water is found at the lower level(i.e. ice tends to float rather than sink). The peculiar freezing property of water protects animals from being frozen, in a cold environment

Dissolved Solids and Quality of Water y

Water of good quality contains 0.25% (2,500 mg/L) dissolved solids. A level up to 1.5% (15,000 mg/L) may be tolerated, provided palatability is not affected. Palatability of water would affect water intake, hence production level. Water may become toxic even before

palatability is not affected particularly when the dissolved solids are harmful. Examples of harmful dissolved substances in water are; nitrates, fluorine, heavy metals, pathogenic microorganisms, algae or protozoa, hydrocarbons, pesticides and industrial chemicals.

Dissolved solids usually represent a source of minerals to the animal. Most common mineral elements present in water are sodium, chloride, calcium, magnesium, sulfates and bicarbonates. Water with sodium chloride above 1 % level is generally not palatable; ruminant cannot tolerate sodium chloride higher than 1 % level in water; swine and poultry cannot tolerate up to 1%. Cattle can tolerate about 1 % sodium chloride under a warm climate or in the dry season. Sulphates at the levels of, 100-200 ppm is considered toxic to different livestock species; 1 g/liter may cause diarrhea.

Tolerance of animals to dissolved substances in water varies with animal species, age, physiological state, dietary level and the season of the year. Animals that are more susceptible to changes in water quality include; dairy cows, sheep/goat, broilers, layers and pigs. The pH of water also affects its quality. Alkaline drinking water may contribute to higher pH in the gut, a condition that favours enteroliths – formation of stones in the large intestines especially in horses. The stones are composed of ammonium, magnesium and phosphorous

Water Intoxication

Animals may be intoxicated from water when body water is replenished without concurrent replacement of electrolytes. Excessive sweating will lead to a simultaneous loss of water and sodium ion concentration.

Replacement of water without electrolytes balance may cause a decline in serum sodium ion concentration under which water migrates to the cells. Symptoms of water intoxication include; loss of appetite, body weakness, muscle twitching and mental apathy.

Inadequate water intake and depletion of extracellular fluids include can lead to low blood volume, low blood pressure, collapse of veins and development of muscle cramps

Unit 3 Carbohydrates

Carbohydrates (Saccharides)

Carbohydrates are poly-hydroxyl aldehydes, polyhydroxyl ketones (substances which yield aldehydes or ketones on hydrolysis) or their derivatives. Carbohydrates usually contain Carbon, Hydrogen and Oxygen in the ratio 1:2:1. Thus carbohydrates can be represented by the simple stoichiometric formula - $(CH_2O)_n$ and referred to in the simplest term as Hydrated Carbon (*hydrate de carbon*, French). The use of $(CH_2O)_n$ formula to represent carbohydrates is an oversimplification as many carbohydrates are modified, and contain amino, sulphate- and phosphate- groups.

Examples of the group of substances referred to as carbohydrates are; sugars, starches, cellulose, gums, pectins, saponins, glucosinolates, cyanogenic glucosides, lectins, glycogen, chitin.

Importance of Carbohydrates

Carbohydrates are very essential molecules to every form of living organism. They form one of the most abundant constituents of plants and animals. Some of the functions of carbohydrates in animals are as;

- a major storehouse of chemical energy for carrying out life processes.
- a source of raw materials for chemical synthesis, e.g. milk is synthesised from two kinds of carbohydrates namely, galactose and glucose.
- essential component of apparatus for genetic control of development and growth in living cells

-ribonucleic acid (RNA) and deoxyribonucleic acid (DNA) contain ribose sugar.

In plants, carbohydrates are supportive structural components e.g. cellulose, lignin, hemicelluloses and protect plants against infections, e.g. polyphenolics, saponins. Lignin is a non carbohydrate component of plant cell wall in strong combination with cellulose and hemicelluloses.

Carbohydrates can be classified as;

- Sugar carbohydrates –They include monosaccharides (sugars with one saccharide unit) and oligosaccharides (sugars with not more than ten monosaccharide units)
- Non-Sugar Carbohydrates, which include polysaccharides (having more than ten monosaccharide units) and complex carbohydrates

The Sugar Molecule

The nature of a sugar molecule is determined by the type of functional group and the position of the side groups it contains. Structural formula of a sugar reveals little information on the nature or type of the sugar

The formula $C_3H_6O_3$ for instance, may be used to represent either of the triose sugars - Glyceraldehyde (an aldose) and Dihydroxyacetone (a ketose).

The structures of some common monosaccharides are as given below.

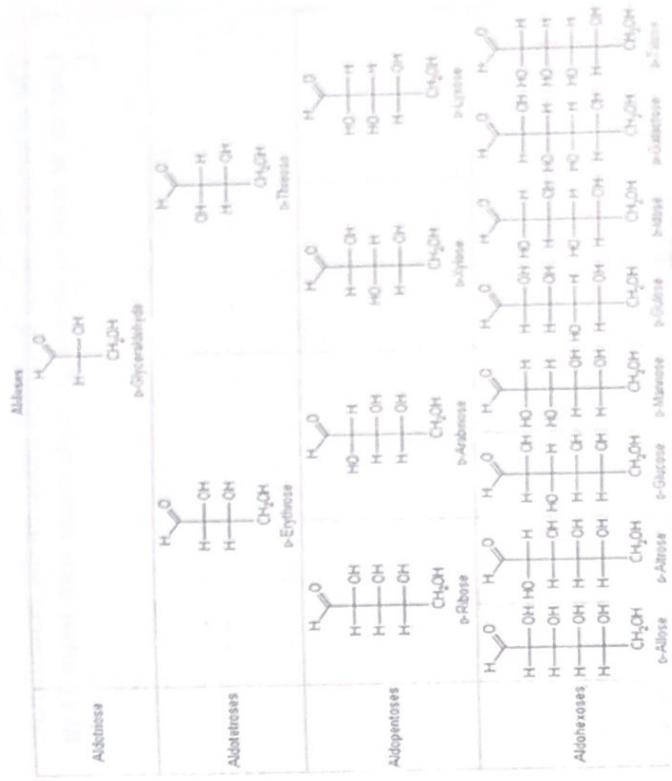


Figure 2: Simple Sugars

Carbonyl group in carbohydrates is denoted by the prefix of **aldo-** for aldehyde; ketone group is denoted by the prefix of **keto-**. Sugars with aldehyde functional group are known as aldoses e.g. Glyceraldehyde, aldopentoses (xylose, ribose); aldohexoses (glucose, mannose, galactose) while sugars with ketone functional groups are ketoses as in Dihydroxyl ketone, DHA; ketopentoses (xylulose, ribulose); ketohexoses (fructose).

D- and L- Sugars

The orientation of the hydroxyl group on the penultimate C-atom is used to denote a simple sugar with letter D or L.

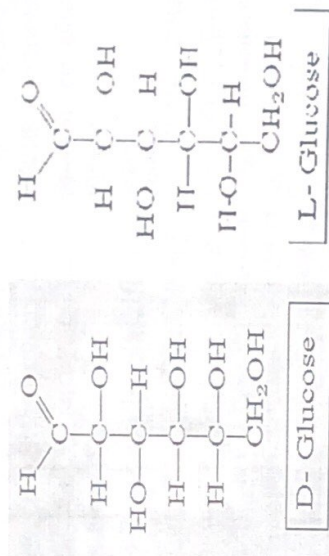


Figure 3: D and L Sugars

Pyranose and Furanose Sugars

Simple sugars exist under physiological conditions primarily in one of two the ring (closed) forms. The ring formed by simple sugars is similar either to a pyran or a furan ring

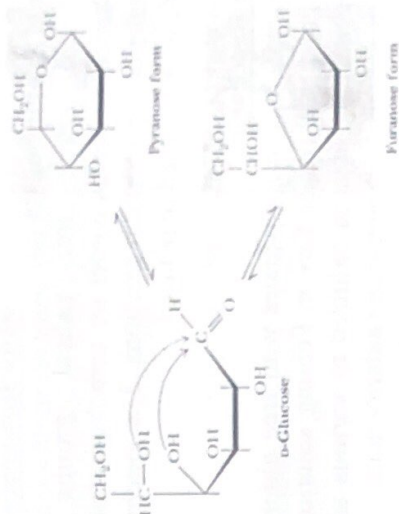


Figure 4: Pyranose and Furanose Sugars

α - and β -Sugars

A pyranose or furanose sugar is identified as α - or β -sugar by the orientation of the hydroxyl group on the anomeric carbon atom in its structure.

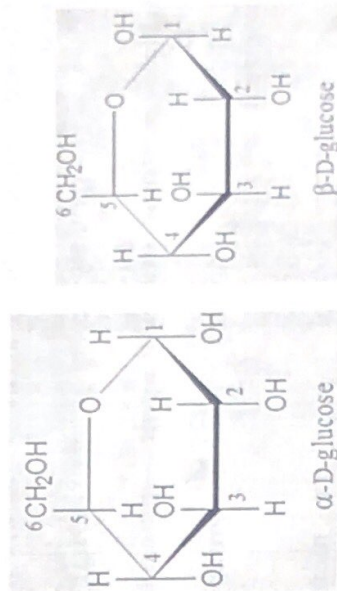


Figure 5: Alpha and Beta Sugar Molecules

Reactions of Simple Sugars

Aldehyde and ketone free radical groups on monosaccharide molecules confer on carbohydrates the ability to take part in chemical reactions. The aldehydes or ketones can be oxidized or reduced

Oxidation Reactions

Sugars and non-sugar carbohydrates with free aldehyde or ketone group will reduce Cu^+ in Fehling solution to Cu^{2+} . The reducing sugar is oxidized to various alpha acids such as aldonic-, alduronic- and aldonic-acid.

- i. **Glucose + weak oxidizing agent $\rightarrow$ gluconic acid**
 - a. (aldehyde group oxidized)
- ii. **Glucose + weak oxidizing agent $\rightarrow$ glucuronic acid**
 - i. (primary alcohol group oxidized)
- iii. **Glucose + strong oxidizing agent $\rightarrow$ glucaric acid**

(aldehyde and primary alcohol groups oxidized)

Primary and secondary alcohol groups are more susceptible to oxidation reactions than primary alcohol group.

Phosphorolization

Aldehyde or primary alcohol carbon may combine with phosphorous to form phosphoric acid ester.

- i. **Glucose + P_i = Glucose-1-phosphate**
- ii. **Glucose + P_i = Glucose-6-phosphate**

Phosphorolization is an important reaction in glucose metabolism.

Formation of Amino Sugars

Free hydroxyl group may combine with amino acid to form amino sugars such as β -D-Glucosamine in chitin and β -D-Galactosamine in cartilage.

Formation of Sugar Alcohol

Aldehyde or ketone group can be reduced to form polyhydric alcohols. e.g.

- i. **Glucose $\rightarrow$ Sorbitol**
- ii. **Fructose/ Mannose $\rightarrow$ Mannitol**

Formation of DeoxySugar

Deoxy-sugars are formed when an hydroxyl (-OH) group on a sugar molecule is replaced by hydrogen as in;

- i. ribose → deoxyribose
- ii. galactose → fucose
- iii. mannose → rhamnose

Formation of Glycoside Bond

A glycoside bond is formed when the hydroxyl group (-OH) on an anomeric C-atom is replaced with an alcohol or sugar molecule or phenol. Each glycoside bond formation is associated with a loss of one molecule of water

Hydrolysis of Oligosaccharide and Polysaccharide

Oligosaccharides and polysaccharides can be hydrolyzed to constituent moieties (monosaccharides, oligosaccharides and non-CHO units) by acid, base or enzyme. Starch/glycogen is hydrolyzed partially to dextrin (water soluble, gum-like substance with a characteristic flavor).

- i. Starch/glycogen(polysaccharide) → Dextrin
- ii. Dextrin → Maltose (disaccharide)
- iii. Maltose → Glucose

CyanogenicGlycosides

Cyanogenic glycosides are complex carbohydrates that can be hydrolyzed to sugar molecules, hydrogen cyanide and non carbohydrate components. Cyanogenic glycosides form important toxic group of carbohydrates due to the rapid release of the toxic hydrogen cyanide component. Examples of cyanogenic glycosides are Linamarin(in linseed, jack bean and cassava) and Dhurrin in sorghum leaves

Stereoisomerism in Carbohydrates

Stereoisomerism is the occurrence of different molecules (of the carbohydrates) having the same number of atoms and the same kind of functional groups but different structural formulae that cause them to behave differently, i.e. same molecular formula but different structural formulae. The molecular formula, $C_6H_{12}O_6$ can be used to represent sixteen different simple sugars; each referred to as **stereoisomer**

Three of the sixteen stereo-isomers of $C_6H_{12}O_6$ are **glucose, mannose and galactose**. The other 13 structures (stereo isomers) do not exist in nature. Differences in the structural formulae are due to different arrangement of the constituent groups of the molecular in space. The sugars may also be differentiated by the position of their functional groups as functional isomers.

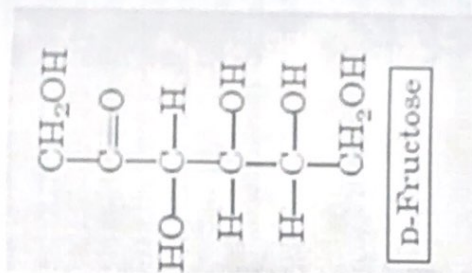
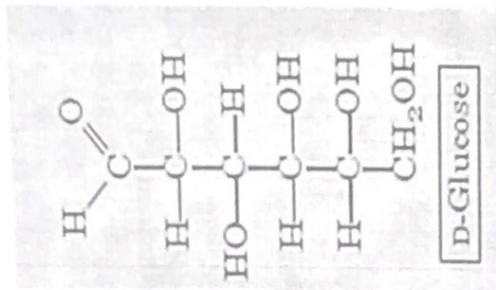


Figure 6: Functional Isomers

Enantiomers

Enantiomers are compounds with the same chemical formula but exist in two different forms in which one of the forms is a mirror image of the other. The phenomenon of enantiomer is common with monosaccharides as they tend to have more than one chiral carbon, hence two types of stereoisomers.

- An example of stereoisomer that are enantiomers are; D- Threose and L- Erythrose.

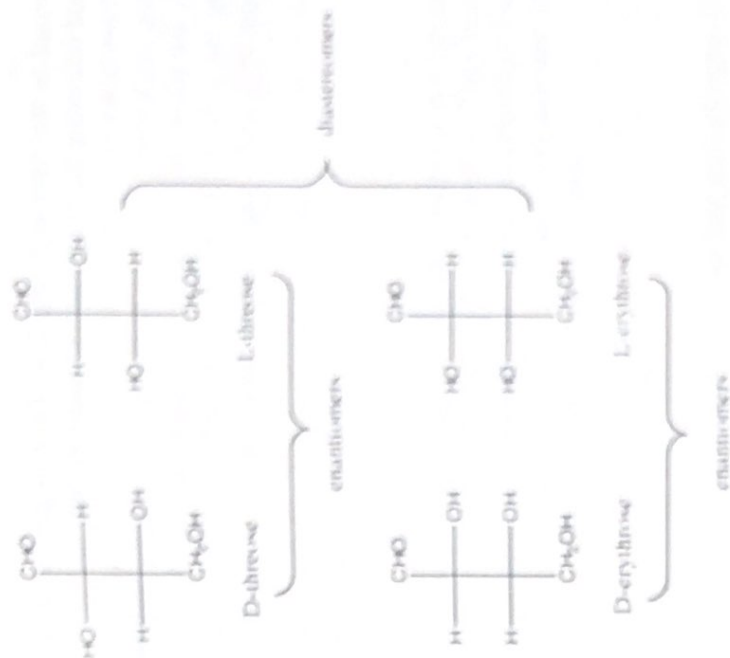


Figure 7: Enantiomers

Dextrorotatory (d-) and Levorotatory (l-) sugars
Carbohydrates exhibit the property of optical activity; they exist as optical isomers. When carbohydrates are placed in a polarimeter, an instrument for studying the interaction of polarized light with optically active substances, the resulting light is either circularly

polarized to the right or to the left. Thus Sugars can be named following the convention of Emil Fisher, as. Dextrorotatory (D-) when the plane polarized light is rotated clockwise (i.e. to the right) or Levorotatory (L-) when the plane rotated counterclockwise (anticlockwise, i.e. to the left). A racemic produced from mixing equal amount of d- and l- sugars are optically inactive.

Unit 4 Lipids

Lipids

Lipids are organic compounds that are sparingly soluble in water but quite soluble in non-polar organic solvents. Organic solvents include chloroform, alcohol, ether, benzene. Lipids have high percentage of carbon atom in their molecules; they make up a high proportion of plants and animals body.

Fat vs. Oil

Fat and oil have similar general structures and chemical properties but differ in physical properties. They exist in solid state at room temperature; oil exists in liquid state. Fat and oil are both found in plants and animals; oil is more abundant in plants than in animals.

Classification of Lipids

Lipids are classified as;

- Neutral Lipids which include acyl glycerol (fat & oil), hydrocarbons, cholesterol and cholesterol esters.
- Phospholipids - phosphatidic acid; phosphatidyl-glycerol/choline/serine/inositol/ethanolamine; sphingomyelin

Lipids can also be classified as;

- Glycerol based lipids - simple lipids (fats & oils); Compound lipids (glycolipids, phospholipids)
- Non glycerol based lipids - sphingolipids; cerebrosides; sterols; waxes; terpenes; postagladings

Structure of Fat/Oil

Fats/Oils are fatty acid esters of trihydric alcohol – glycerol.

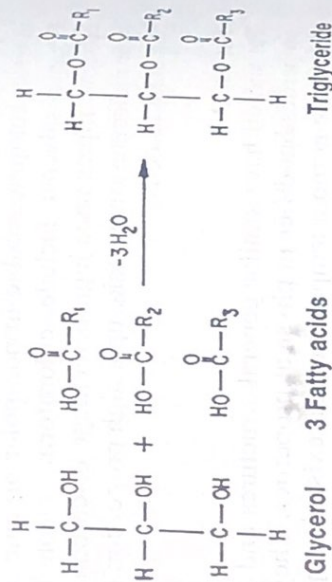


Fig. 2.6. Lipids.

Figure 8: Structure of Triacylglyceride

R_1 , R_2 and R_3 can be the same or different fatty acids, saturated or unsaturated

Fatty acids can be described as short chain (2-6 carbon atoms; also called the volatile fatty acids), medium chain (8-12 Carbon atoms) or long chain (14-24 Carbon atoms). Fatty acids can also be described as Saturated (without a double bond), monounsaturated (one double bond) or polyunsaturated (more than one double bond).

Table 1: Fatty Acid Nomenclature

Systematic name	Trivial name	Shorthand designation
<i>cis</i> -9-tetradecenoic	myristoleic	9-14:1 or 14:1(<i>n</i> -5)
<i>cis</i> -7-hexadecenoic		7-16:1 or 16:1(<i>n</i> -9)
<i>cis</i> -9-hexadecenoic	palmitoleic	9-16:1 or 16:1(<i>n</i> -7)
<i>cis</i> -6-octadecenoic	petroselinic	6-18:1 or 18:1(<i>n</i> -12)
<i>cis</i> -9-octadecenoic	oleic	9-18:1 or 18:1(<i>n</i> -9)
<i>cis</i> -11-octadecenoic	<i>cis</i> -vaccenic	11-18:1 or 18:1(<i>n</i> -7)
<i>cis</i> -11-eicosenoic	gondoic	11-20:1 or 20:1(<i>n</i> -9)
<i>cis</i> -13-docosenoic	erucic	13-22:1 or 22:1(<i>n</i> -9)
<i>cis</i> -15-tetracosenoic	nervonic	15-24:1 or 24:1(<i>n</i> -9)
<i>trans</i> -3-		3-18:1

hexadecenoic

trans-9-elaidic 9 α -18:1

trans-11-
vaccenic
octadecenoic

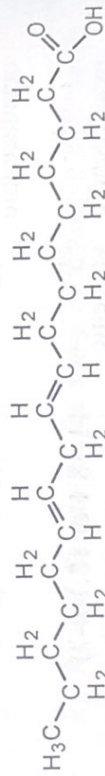
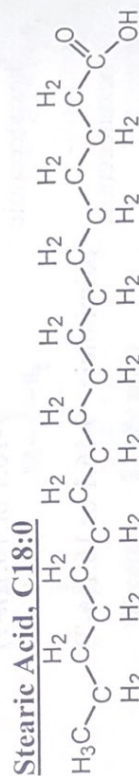


Table 2: Common Food Sources of Fatty Acids

Acids	Carbons	Double bonds	Abbreviation	Source
Acetic	2	0	2:0	bacterial metabolism
Propionic	3	0	3:0	bacterial metabolism
Butyric	4	0	4:0	butterfat
Caproic	6	0	6:0	butterfat
Caprylic	8	0	8:0	coconut oil
Capric	10	0	10:0	coconut oil
Lauric	12	0	12:0	coconut oil
Myristic	14	0	14:0	palm kernel oil
Palmitic	16	0	16:0	palm oil

Palmitoleic	16	1	16:1	animal fats
Stearic	18	0	18:0	animal fats
Oleic	18	1	18:1	olive oil
Linoleic	18	2	18:2	grape seed oil
Linolenic	18	3	18:3	flaxseed (linseed) oil
Arachidonic	20	4	20:4	peanut oil, fish oil

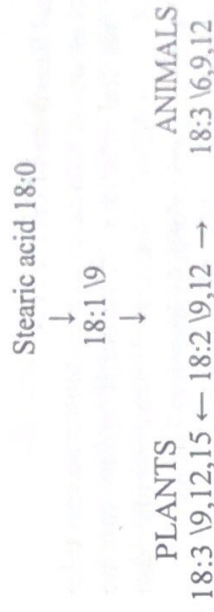
Essential Fatty Acids

Animals lack the enzyme required to introduce double bond between C-atom 12 and 13. Certain fatty acids are known to alleviate symptoms of poor growth & skin lesions in animals on fat-free diets.

- Linoleic acid (18:2 \9,12) – Omega-6- fatty acid
- alpha linolenic acid (18:3 \9,12,15) -) mega3-fatty acid
- gamma linolenic acid (18:3 \5,8,11,14)

Gamma linolenic acid and arachidonic acid (not found in plants) are more active than alpha linolenic acid; they can also be synthesized from linoleic acid (C18:2) in most mammals except cat. Animals unlike plants cannot synthesize linoleic and alpha linolenic acid. The two essential fatty acids in animals are therefore; LINOLEIC ACID (18:2 \9,12) and Alpha LINOLENIC ACID (18:3 \9,12,15). The two fatty acids are essential in diets as they can only be by animals from a dietary source.

Production of Essential Fatty Acids



Desaturation towards methyl group. Desaturation -towards carboxyl group

Fatty acids with double bonds in positions 6-7, 9-10 are more effective in relieving symptoms of fatty acid deficiency

LINOLEIC ACID



18:2 n-6

LINOLENIC ACID



18:3 n-3

EICOSAPENTAENOIC ACID



20:5 n-3

Chemical Reactions of Fats & Oils

Carboxyl groups of fatty acids in a fat molecule can take part in chemical reactions. A carboxyl group can be esterified or reduced. Unsaturated fatty acids can undergo addition reaction with hydrogen or halogen.

Saponification

Saponification number of fat/oil is the number of mg of KOH needed to convert 1 g of fat to soap and glycerol..

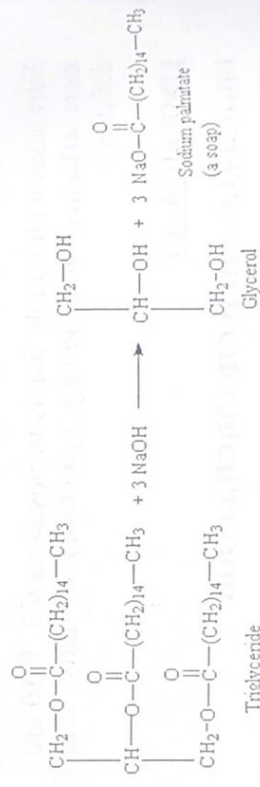


Figure 9; Saponification Reaction

Lipolysis

Lipolysis is the hydrolysis of fat molecule to release glycerol and fatty acids in the presence of lipase enzyme and water. Lipase enzyme may be specific for a particular fatty acid on the fat molecule; fatty acid in the second carbon is often more susceptible to lipolysis.

Hydrogenation

Hydrogenation of fat is the addition of hydrogen to double bonds of unsaturated fatty acids in the fat molecule.



Hydrogenation as a hardening process is important in the production of hard fat such as margarine from vegetable oils. The mainly unsaturated fatty acids (linoleic and linolenic acids) in the diets of ruminants are also hydrogenated to stearic acid by microorganisms in the rumen. Hydrogenation is the main reason why body fat of ruminants is highly saturated even if high level of unsaturated fatty acids is fed

Iodine Number

Iodine number is the number of g of iodine that is absorbed by 100 g fat/oil sample. It measures the degree of saturation of fat/oil.

Rancidity in Fats and Oils

The presence of double bonds makes unsaturated fatty acids susceptible to auto-oxidation in the presence of

light or metal ions. The process of auto-oxidation involves;

- Hydrogen ion on the C-atom adjacent to the double bond is abstracted by a free-radical in the medium to yield a new radical.
- The new radical combines with O_2 to form a peroxy-radical
- Peroxy-radical also abstract Hydrogen from another fatty acid molecule to produce a hydroxyperoxide.
- Hydroxyperoxide is cleaved to two radicals or decompose to keto or hydroxyketo acid

The release of short-chain fatty acids (e.g. butyric acid) and fatty aldehydes during the breakdown is responsible for the offensive odour that is associated with rancidity. Oxidation of saturated fatty acids will produce methyl ketone which has a sweet taste and smell; caproic acid is oxidized to pentanone.

Antioxidants

Natural fats possess some level of antioxidants which reduce oxidation of fatty acids. Synthetic antioxidants are also available and may be added to fats and oils. They include Butylated HydroToluene, BHT; Butylated Anisole; Vitamin E. The vitamin is a strong antioxidant which prevents lipolysis by taking up free radicals. The lipid oxidation process is autocatalytic, the concentration of free radicals however, will increase to a level at which they will attack each other and terminate the process.

Unit 5 Proteins

Amino Acids

Amino acids are the building blocks of polypeptides and proteins. There are more than 200 different amino acids in nature; about 20 different amino acids are found in most of proteins. Structurally an amino acid consists of a basic amino group ($-NH_2$) and an acidic carboxylic group ($-COOH$) group with a side chain, $-R$

Table:3 Structures of Amino Acids

Amino Acid Name	Abrv	Abrv	Structure of R group (red)	Comments
Alanine	ala	A	$\begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{CH}_3 \\ \\ \text{CH}_3 \end{array}$	Neutral Non-polar
Arginine	arg	R	$\begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{O}^- \\ \\ (\text{CH}_2)_3-\text{N}^+ \end{array}$	Basic Polar
Asparagine	asn	N	$\begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{O} \\ \\ \text{CH}_2-\text{C}(=\text{O})-\text{NH}_2 \end{array}$	Neutral Polar

Aspartic Acid	asp	D	$\begin{array}{c} \text{H O} \\ \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{O}^- \\ \\ \text{CH}_2\text{CO}_2^- \end{array}$	Acidic Polar
Cysteine	cys	C	$\begin{array}{c} \text{H O} \\ \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{O}^- \\ \\ \text{CH}_2\text{SH} \end{array}$	Neutral Slightly Polar
Glutamic Acid	glu	E	$\begin{array}{c} \text{H O} \\ \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{O}^- \\ \\ \text{CH}_2\text{CH}_2\text{CO}_2^- \end{array}$	Acidic Polar
Glutamine	gln	Q	$\begin{array}{c} \text{H O} \\ \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{O}^- \\ \\ \text{CH}_2\text{CH}_2\text{CONH}_2 \end{array}$	Neutral Polar
Glycine	gly	G	$\begin{array}{c} \text{H O} \\ \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{O}^- \\ \\ \text{H} \end{array}$	Neutral Non-polar
Histidine	his	H	$\begin{array}{c} \text{H O} \\ \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{O}^- \\ \\ \text{CH}_2\text{CH}(\text{NH})\text{CH}_2\text{CH}_3 \end{array}$	Basic Polar
Isoleucine	ile	I	$\begin{array}{c} \text{H O} \\ \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{O}^- \\ \\ \text{H}_3\text{C}-\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}_3 \end{array}$	Neutral Non-polar

Leucine	leu	L	$\begin{array}{c} \text{H O} \\ \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{O}^- \\ \\ \text{CH}_2\text{CH}(\text{CH}_3)_2 \end{array}$	Neutral Non-polar
Lysine	lys	K	$\begin{array}{c} \text{H O} \\ \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{O}^- \\ \\ \text{CH}_2(\text{CH}_2)_4\text{NH}_3^+ \end{array}$	Basic Polar
Methionine	met	M	$\begin{array}{c} \text{H O} \\ \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{O}^- \\ \\ \text{CH}_2\text{CH}_2\text{SCH}_3 \end{array}$	Neutral Non-polar
Phenylalanine	phe	F	$\begin{array}{c} \text{H O} \\ \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{O}^- \\ \\ \text{CH}_2\text{CH}(\text{C}_6\text{H}_5) \end{array}$	Neutral Non-polar
Proline	pro	P	$\begin{array}{c} \text{O} \\ \\ \text{HC} \\ \\ \text{H}_2\text{N} \end{array}$	Neutral Non-polar
Serine	ser	S	$\begin{array}{c} \text{H O} \\ \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{O}^- \\ \\ \text{CH}_2\text{OH} \end{array}$	Neutral Polar
Threonine	thr	T	$\begin{array}{c} \text{H O} \\ \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{O}^- \\ \\ \text{CH}(\text{CH}_3)\text{CH}_2\text{OH} \end{array}$	Neutral Polar

Unit 12

Energy in Metabolism

Feed Energy

Energy is the capacity to do work; it is an important item in animals' diets. Radiant energy of the sun is converted by green plants to produce complex constituents which are stored. (Anabolism; a synthetic reaction). Animals consume plants and break down complex constituents are broken down to release energy which is used to provide mechanical work, synthesis, heat etc. Animals derive energy from partial or total hydrolysis of organic molecules in foods. Energy exists in different forms which include; 1) Potential-, 2) Chemical-, 3) Heat-, 4) Electrical- and 5) Radiant-energy

The different forms of energy are inter-convertible using appropriate means

The 2 laws of thermodynamics are applicable in metabolism: 1) when one form of energy is converted to another, there is no loss or gain in energy. 2) When one form of energy is converted to another a proportion of it is turn into heat.

Heat unit is used to measure the different forms of energy in metabolism. The basic unit of energy is the Calorie. A Calorie is the quantity of heat energy required to raise the temperature of 1 g H₂O from 14.5° C to 15.5° C. Calorie is accurately standardized and defined as 4.1855 (International) Joules

However, the calorie is inconveniently small for use in nutrition as large amounts of energy are involved. Therefore energy units that are often used in metabolism include;

- Kilo-calorie = 10^3 calories
- Mega-calorie = 10^6 calories
- Joules = 0.2389 calorie
- Kilojoules = 10^3 joules
- Mega joules = 10^6 joules

Quiz

Why is the same energy unit used for measuring heat also use to measure energy in metabolism?
(- all forms of energy are inter-convertible!)

Types of Chemical Reactions

The proportion of heat change which is available to do work is termed Free Energy Change represented as ΔG . The two main types of chemical reactions are Exergonic reactions and Endergonic reactions.

A reaction is said to be exergonic, if ΔG is negative; it is endergonic when ΔG is positive. Most of the synthetic reactions in the body are endergonic. The energy to drive endergonic reactions are obtained from the catabolic exergonic reactions.

Sources of Chemical Energy

The form of energy useful to the animal is the chemical energy. (-for plants, it is solar energy). Any substance with carbon-hydrogen bonds has the potential of being use to produce chemical energy. Chemical energy in feeds is transformed during catabolism of the products of digestion— hexoses, fatty acids, glycerol, amino acids pentoses, or amines to high energy molecules. The major

sources of energy in metabolism are however, carbohydrates and fatty acids. Animals on high protein diet may use dietary amino acids for energy production as in starvation or when the diet is also energy restricted would mobilize tissue amino acids for energy production.

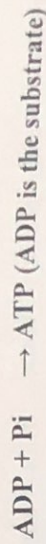
The Role of Mediating Compounds in Metabolism

Mediating compounds help to establish a connection between the two aspects of metabolism (anabolism - endergonic reactions and catabolism-exergonic reactions). Energy release during exergonic reactions cannot diffuse through the cell to take part in metabolic reactions. Certain mediating compounds pick up energy from exergonic reactions and transfer energy to endergonic reactions.

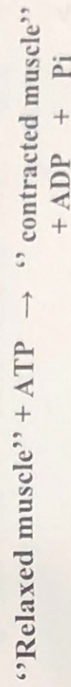
Mediating compounds include certain nucleotides that take part in the reactions: phosphorylated purines- (Guanine, Adenosine) & pyrimidines- (Cytosine & Uracil). The most important mediating compounds are; AMP, ADP, ATP

Substrate Level Phosphorylation

Phosphorylation reaction in metabolism is the transfer of phosphate group from a phosphate-group containing compound to ADP to form ATP. During phosphorylation a phosphate of high potential gives its phosphate group to ADP.



ATP is universally used by all forms of life as the principal carrier of free energy for bodily functions; almost every energy-demanding activity consumes ATP - other nucleotides are occasionally used as carriers of free energy. Regeneration of ATP is a principal purpose of catabolism.



Oxidative Phosphorylation

Apart from the phosphate group transfer potential, the body produces ATP from compounds with high electron transfer potential. ATP is generated through the electron transfer/transport chain.

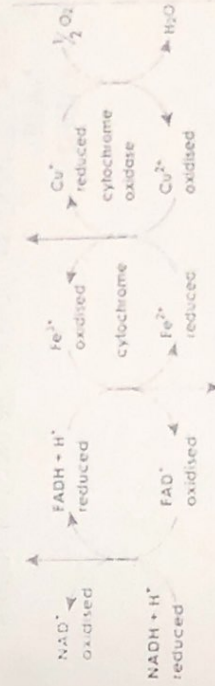


Figure 12: Electron Transport Chain

The electrons and protons come from energy metabolites, intermediate in the catabolism of sugars and fatty acids; electrons of -C-H- bonds are generally used. Respiratory enzymes in the respiratory chain are the chief receptors of hydride group in the oxidative phosphorylation reactions.

The chief respiratory enzymes are those having as coenzymes;

- NAD⁺
- FAD – a riboflavin linked by a -PO₄ to an AMP unit
- FMN – flavin mononucleotide – a -PO₄ ester of riboflavin
- CoQ -

Respiratory enzymes also include a series of heme-containing enzymes having iron ions (the last of them holds a copper ion). The enzymes work together in packages called respiratory assemblies located on the inner surface of the mitochondria – the power house of the cell.

Electron acceptors include FMN, ubiquinone (CoQ), and proteins known as cytochromes.

Oxidative Phosphorylation contain the electron donors

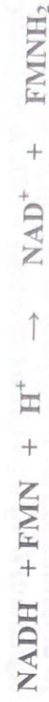
- NADH + H⁺
- FADH₂

The coupled oxidation/reduction reaction can be represented as;



The coupled reactions yield free energy.

NADH + H⁺ yields 52 Kcal/mole since electrons transfer from NADH + H⁺ to oxygen yields 3 ATP molecule at 3 sites. FADH₂ yields 36 Kcal/mole as electrons transfer from FADH₂ to oxygen yields 2 ATP molecule at 2 sites.



Reduced FMN gives up H to CoQ:



Reduced CoQ passes electron to cytochrome b which later passes electrons to cytochrome c₁ → cyt c₂ → cyt₃ and finally to O₂.

Energy Partitioning in Metabolism

The heat energy in foods can be described in terms of;

- Gross energy
- Digestible energy
- Metabolizable energy
- Net energy
- Total Digestible energy

Gross Energy

Gross energy is the quantity of heat resulting from complete oxidation of unit weight of a food. It is the heat of combustion of a substance usually measured in a bomb calorimeter.

Digestible Energy

Digestible energy is the gross energy of a food minus the gross energy of the faeces resulting from consumption of a unit weight of the food.

$$DE = GE (\text{food}) - GE (\text{faeces})$$

Metabolizable Energy

Metabolizable energy is the gross energy in food minus energy loss through faeces minus energy loss through urine.

$$\begin{aligned} ME &= GE (\text{food}) - GE (\text{faeces}) - GE (\text{urine}) \quad \text{i.e. } ME \\ &= DE - GE (\text{faeces}) \end{aligned}$$

Net Energy

Net energy is the energy available for maintenance or production following consumption of a food. It is calculated as the difference between ME and energy loss in rumen fermentation and tissue metabolism.

NE is calculated for different physiological states of the animal (NE_m; NE_g; NEI etc.)

Total Digestible Energy, TDN

TDN is the energy in food estimated from digestible nutrients. It is the sum of digestible crude protein, crude fibre, nitrogen free extract (CHOs) plus ether extract (lipid) $\times 2.25$

$$TDN = \text{Digestible } (CP + CF + NFE + 2.25 EE)$$

Unit 13

Carbohydrate Metabolism

Glucose as an Energy Source

Complete oxidation of glucose occurs in three principal stages;

- Glycolysis
- Pyruvate oxidation
- Acetyl-CoA oxidation

Steps of Reactions in Glycolysis

1. Glucose is phosphorylated by ATP – the step is essentially irreversible; it traps glucose inside the cell.
2. G-6-P undergoes isomerization to Fructose-6-Phosphate; the reaction is catalyzed by an isomerase.
3. ATP transfers its phosphate unit to Fructose-6-Phosphate to make Fructose-1,6-diphosphate; the reaction is essentially irreversible.
4. Hexose diphosphate breaks into 2 triose-phosphates; the reaction is catalyzed by an aldolase.
 - Isomerization reaction between the two triose-phosphates ensures that all the chemical energy in glucose can be obtained.
 - The main path continues with Glyceraldehyde-3-Phosphate.
5. Oxidative phosphorylation occurs; NAD^+ is reduced to NADH; an aldehyde group in GHD-3-P is oxidized to carboxyl state on to which an inorganic phosphate is attached.

6. 1,3-diphosphoglycerate has a higher $-\text{PO}_4$ group transfer potential than ATP; it gives a $-\text{PO}_4$ group to ADP; the initial investment of ATP is refunded plus 1 ATP.
7. The $-\text{PO}_4$ group in 3-P-glycerate shifts to the 2 position
8. Dehydration of 2-P-glycerate is like cocking a huge bioenergetic gun; it converts a low energy $-\text{PO}_4$ into the highest-energy $-\text{PO}_4$ in all metabolic reactions, i.e. the $-\text{PO}_4$ ester of the enol form of pyruvate Phosphoenolpyruvate, PEP
9. ATP is formed as $-\text{PO}_4$ group transfers from PEP to ADP; the loss of a $-\text{PO}_4$ groups from PEP creates an instability which drives the reaction

Under Aerobic Condition

In the presence of oxygen, pyruvate is changed to acetyl-CoA which enters the TCA cycle to restore the reduced enzyme with NADH at step 5; NADH can pass off H to the respiratory chain

Under anaerobic condition

Glycolysis must shut down unless the reduced NADH-enzyme at step 5 can change back to NAD^+ . The change in the absence of O_2 and the operation of the respiratory chain occurs by the reduction of pyruvate to Lactate. Hence, lactate is the end product of glycolysis under anaerobic condition

Summary of ATP Production from Glycolysis

- 2 moles of ATP are used in the initial phosphorylation of steps 1 and 3
- Fructose-1,6-diphosphate breaks down to give 2 moles of GHD-3-Phosphate
- Subsequently an NAD^+ linked dehydrogenation at step 5 is supposed to yield 3 moles of ATP but yields 2 ATP instead (the need for Glycerol phosphate shuttle)
- 1 mole of ATP is produced directly at each of steps 6 and 9
- 8 moles of ATP are thus produced from 1 mole of glucose; 2 moles of ATP are used up giving a net production of 6 moles of ATP per mole of glucose

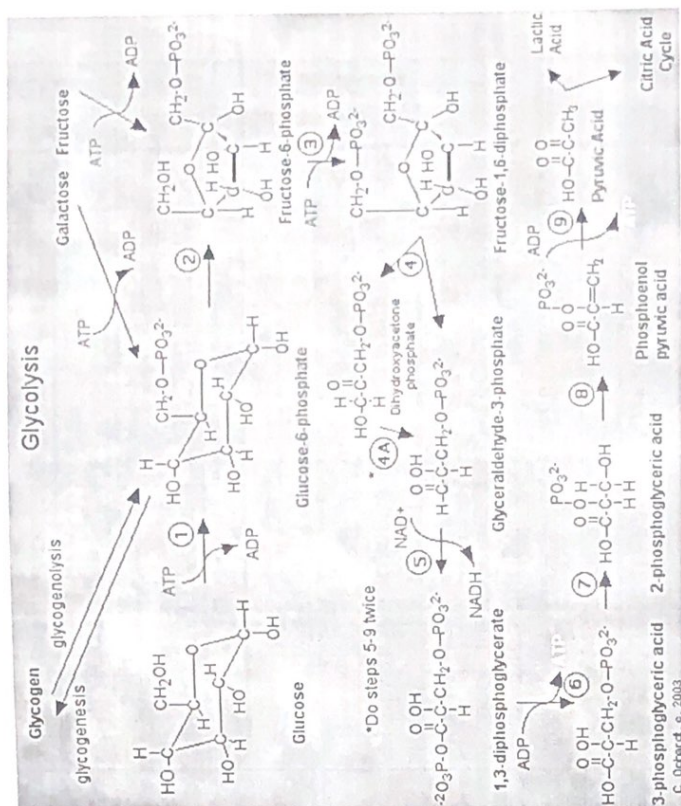
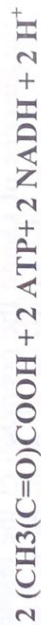


Figure 13: Glycolysis Metabolic pathways

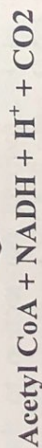
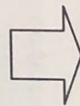
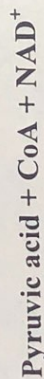
As a result of the indirect connection to the electron transport at FAD, only 2 ATP are made per NAD^+ used in step 5.

Quiz Time

Starting from glucose (6-C) how many ATP are made using aerobic glycolysis? (Ans = 6)
 Starting from glucose (6-C) how many ATP are made using anaerobic glycolysis? (Ans = 2)

Oxidative Decarboxylation of Pyruvate

Under aerobic conditions the end product of glycolysis is pyruvic acid. The next step is the formation of acetyl coenzyme A (acetyl CoA) which is the initiator of the citric acid cycle. In carbohydrate metabolism, acetyl CoA is the link between glycolysis and the citric acid cycle. The overall formation reaction of acetyl CoA may be represented as:



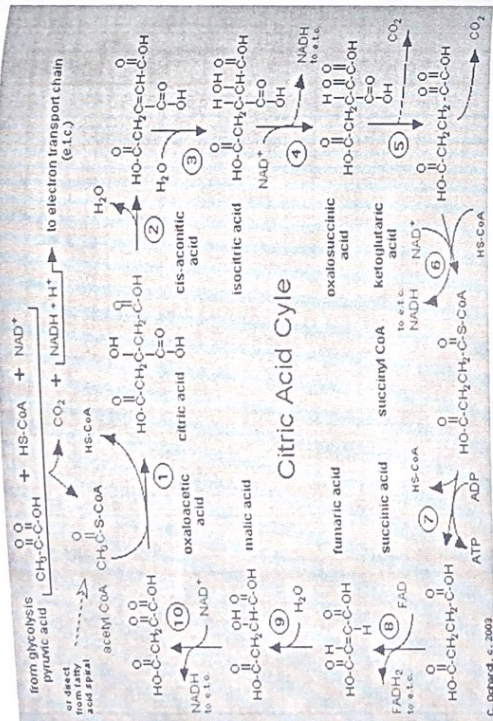
The reduced form, NADH, initiates the respiratory chain to regenerate NAD^+ . The specific enzyme involved in the decarboxylation reaction, pyruvate dehydrogenase contains thiamine pyrophosphate (TPP) as a coenzyme.

The Tricarboxylic Acid Cycle, TCA

Tricarboxylic Acid Cycle, TCA also referred to as the Citric Acid Cycle, CAC is the most important part of metabolism; all of the other types of metabolism feed into TCA cycle. The TCA cycle is the most important link to the electron transport chain, ETC where most of the ATP needed for energy reactions is produced.

Reactions of the TCA Cycle

- The initiating step of the citric acid cycle occurs when a four carbon compound (oxaloacetic acid) condenses with acetyl CoA (2 carbons) to form citric acid (6 carbons). The source of acetyl CoA is glycolysis or the fatty acid spiral(lipids)
- As the cycle proceeds, 2 carbons are converted into two CO_2 molecules at steps 5 and 6.
- The cycle has a series of oxidation reactions which are accompanied by the loss of hydrogen and electrons at four specific places.
- These oxidations are connected to the electron transport chain where many ATP are produced.
- Reactions 4, 6, and 10 involve oxidations of an alcohol group to a ketone group with the coenzyme NAD^+ , which result in the removal of 2 hydrogen and 2 electrons.
- NAD^+ is the entry point into electron transport chain. (starting with NAD^+ , production of 3 ATP results from each use of the electron transport chain).



12/16/2010

Figure 14: TCA Cycle

Production of ATP from one Turn of the Citric Acid Cycle

ATP from NAD⁺ through ETC

Steps 4 = NAD⁺ = 3 ATP
 Steps 6 = NAD⁺ = 3 ATP
 Steps 10 = NAD⁺ = 3 ATP
ATP from NAD⁺ = 9 ATP

ATP from FAD through ETC

- Step 8 is another oxidation involving the coenzyme FAD.
- Since FAD is part of the second enzyme complex, only 2 ATP are made with the electron transport chain. Step 8 = **FAD = 2 ATP**
- In the citric acid cycle, there is only one reaction which directly produces an ATP and this is at step 7 = **1 ATP**

NET ATP Production = 9 + 2 + 1 = 12 ATP

Summary of ATP Production from Oxidation of Pyruvic Acid in TCA Cycle

Step	Reaction	H-H	ATP
1	Pyruvate → Acetyl-CoA	NAD ⁺	3
4	Isocitrate → Oxaloacetate	NADP ⁺	3
6	Ketoglutarate → Succinyl-CoA	NAD ⁺	3
7	Succinyl-CoA → Succinate	-	1
8	Succinate → Fumarate	FAD ⁺	2
10	Malate → Oxaloacetate	FAD ⁺	3
Total ATP			15

Efficiency of Free Energy Capture – via TCA

A total of 36 phosphate bonds are formed when 1 mole of glucose is oxidized via the CAC. Each phosphate bond yields approximately 12.5 Kcal of energy when broken by hydrolysis under physiological conditions, i.e. A mole of glucose when oxidized would yield a total of 450 Kcal of energy in a utilizable form.

Total free energy of glucose at 37°C is 703 Kcal/mole. Therefore, the efficiency of free energy capture by the body is $450/703 \times 100 = 64.01\%$

Quiz Time

1. Starting with one pyruvic acid, how many ATP are made through the citric acid cycle? (15 ATP)
2. Starting with glycogen to make glucose-6-phosphate, how many ATP are made using aerobic glycolysis pathway? (7 ATP)
3. Starting with glycogen to make glucose-6-phosphate, how many ATP are made using aerobic glycolysis and the citric acid cycle? (37 ATP)

The Hexose Phosphate Shunt

An alternative pathway of glucose oxidation is the hexose phosphate shunt which involves the addition of water to phosphorylated glucose followed by a series of NADP^+ linked dehydrogenation reactions.

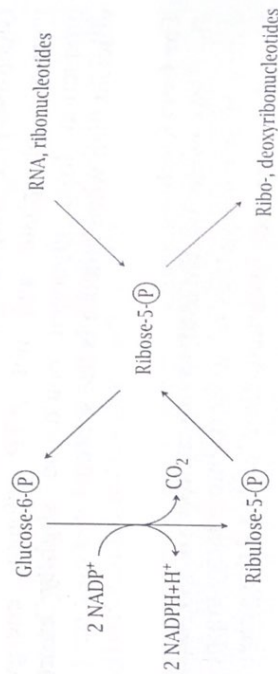


Figure 15: The Hexose Phosphate Shunt

The hexose phosphate shunt may be summarized as;



Oxidation of H-H via the NADP^+ pathway yields 36 high phosphate bonds. The initial phosphorylation of glucose consumes 1 mole of ATP leaving a net production of 35 high phosphate bonds per mole of glucose. Efficiency of free energy capture would be $12.5 \times 35/703 \times 100 = 62.3\%$.

Hexose phosphate shunt is important in the muscles where a supply of reduced NADP^+ rather than NADH is required

Glycogen as Energy Source

Glucose apart from being obtained from digestive tract may become available for oxidation from the reserve of glycogen in the body. Glycogen or the animal starch is made up of several molecules of glucose. Glucose-6-phosphate is produced by the action of inorganic phosphate and not ATP. Hence, energy production from glycogen could be slightly more efficient than when glucose is the source.

The Cori Cycle

The Cori cycle which lead to utilization of glycogen during muscular activities for a short time energy supply. Muscular activity or its anticipation leads to the release of epinephrine by the adrenal medulla. The epinephrine thus released would stimulate glycogen breakdown in muscles and, to a lesser extent, in the liver. As the muscular activity quickly uses stored ATP as the source of energy, additional ATP must be generated by the breakdown of glycogen.

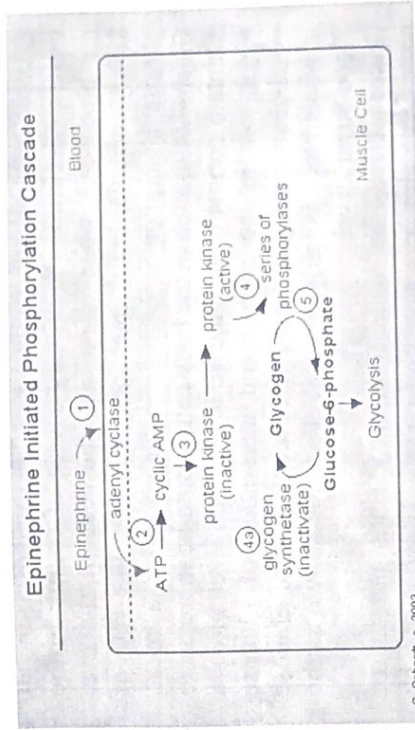
Glycolysis at the early part of the muscular activity, produces pyruvic acid which is then converted into acetyl-CoA and is metabolized in the citric acid cycle to make ATP using the electron transport chain. As the muscular activity is extended, the availability of oxygen for use at the end of the electron transport chain becomes the limiting factor after the cells have exhausted the oxygen available to the muscle. The citric acid cycle is inhibited in the absence of oxygen and pyruvic acid accumulates.

Accumulation of lactic acid from pyruvic acid which occurs eventually is the final limiting factor in continued

muscular activity. Lactic acid produces muscular pain and cramps that would force discontinuation of the activity. Lactic acid diffuses out of the muscle cells and into the blood where it enters the liver at the onset of pain and after muscular activity is stopped. The process of recycling lactic acid is referred to as the

Cori Cycle.

Glycolysis is a significant source of ATP when muscular activity continues for any length of time



C. Ophardt, e., 2003

Figure 16: The Cori Cycle

In order for most of the lactic acid to be converted to glucose, a quantity of the acid must be converted to pyruvic acid and then to acetyl CoA (step 7). The citric acid cycle and electron transport chain must also provide ATP to "fuel" the gluconeogenesis of the remainder of the lactic acid to glucose.

Significance of Glucose Metabolism

Controls blood glucose concentrations

Glucose metabolism enables the body to effectively control blood sugar levels in starvation, during physical exercise, when the animal is stressed and immediately after a meal. A high blood sugar can damage eye lens and kidney tissues. Low blood glucose concentration will equally cause damages to the brain and eventually death.

Energy Source to the Cell

Glucose metabolism facilitates ATP synthesis in all tissues. Glucose is the primary source of energy in the red blood cell, white blood cell, the cells of the eye, kidney medulla, brain, intestines and skin. The rate of glucose absorption is high immediately after a meal. Glucose utilization in the body cells would be increase to maintain normal blood glucose levels. The liver plays a major role in the control and integration of glucose metabolism among tissues. The concentration of glucose in whole blood is fairly constant at a value known as the Blood Sugar Level.

Glucose cannot be made from fatty acids but fat or protein can also be a source of energy. Glucose can be made from most amino acids (but not from leucine), short chain fatty acids (e.g. propionate) or glycerol

Quiz Time

Is Glucose strictly an essential nutrient?

Hypoglycemia and Hyperglycemia

Hypoglycemia is the condition where the concentration of glucose in the blood is below the normal fasting level. The condition of hypoglycemia may starve the brain of energy as it does not store glycogen. Hyperglycemia occurs when the concentration of blood glucose rises above the fasting level. The concentration of glucose in the blood above which the kidney begins to transfer excess glucose to the urine is called the renal threshold for glucose.

Factors that Raise Blood Glucose Concentration

- Hunger
- Glucose absorption from gut
- Hepatic glycogenolysis
 - Adrenaline
 - Glucagon
- Gluconeogenesis in the liver
- Insulin antagonist
 - Growth Hormone
 - Cortisol
- Insulin destroying enzymes

Factors that Lower Blood Glucose concentration

- Satiety
- Glucose diffusion in extracellular fluid, ECF
- Muscular exercise
- Insulin
 - increases glucose oxidation
 - increases glycogen deposition
 - increases lipogenesis
 - decreases gluconeogenesis

Unit 14

Lipid Metabolism

Roles of Lipids

Fat depots

The fat depots cushion organs against sharp jolts and bumps. Fat depots also insulate organs against sudden variation in temperature. Some active metabolic reactions also occur in fat depots to generate additional heat energy in cold weather.

Essential Fatty Acids

A minimum amount of lipid is essential in the diet to provide in the diet of an animal both for some critical physiologic processes and as a carrier for fat soluble vitamins

Tri-acyl glycerol

Fatty acids derived from hydrolysis of triacyl glycerol may be the primary source of energy for many tissues, usually preferred to carbohydrates in certain organs. Fatty acid is the most concentrated form in which energy can be stored – its calorific value (38.9 KJ/g) is over twice as great as that of carbohydrate or protein. The fatty acids provide more metabolic water upon oxidation than other metabolic fuels – an advantage to mammals in hot dry climate.

Lipids of metabolic significance

Lipids that are significant in metabolism include;

- Triacyl glycerols (neutral fats)
- Free Fatty Acids

- Glycerols
- Ketone bodies
- Phospholipids
- Steroids

Blood, Liver and Tissue as Energy Reserves

The free glucose in the blood provides energy reserve that is only enough to maintain body functions for a few minutes. Glycogen stored in the liver and muscles can maintain body functions for about one day without new inputs of food. Finally, lipid reserves in fat depots can maintain body human body functions without food for 30-40 days with sufficient water. Protein (mostly in muscle) is a potential energy reserve.

Control of Lipids Level in the Blood

Lipids are not soluble in blood; they are transported as lipoproteins after reaction with water-soluble proteins in the blood; fatty acids are also generally transported as lipoproteins. Blood lipid levels increases immediately after a meal. A relatively constant supply of lipids in the blood is always maintained. The liver is responsible for providing the proper concentrations of lipids in the blood. Lipids in the blood are absorbed by liver cells to provide energy for cellular functions. Some lipids are utilized by brain cells to synthesize brain and nerve tissue.

Excess lipids in the blood are eventually converted into adipose tissue. If lipid levels in the blood become too

low, the body synthesizes lipids from other foods, such as carbohydrates, or removes lipids from storage. The body also excretes some lipids in the form of fats, soaps, or fatty acids as a normal component of feces. Abnormally high levels of triglycerides and cholesterol are thought to be involved in hardening of the arteries. Lipids may be deposited on the walls of arteries as a partial consequence of their insolubility in the blood.

Fat Deposition in Adipose Tissue

The principal lipid depots in an animal are the adipose tissue; lipids are also deposited in nearly all parts of the body. Lipids on reserve in adipose tissue come largely from dietary carbohydrates and lipids. About 30 % of dietary carbohydrates is converted to fat; another 25 % is used to generate ATP to power the conversion. Hence a significant portion of oxygen consumption and heat production in the body goes into fat deposition in the adipose tissue. Lipids composition in fat depot is dynamic – old fat units are replaced with newly formed fat molecules. Fat depot occurs as subcutaneous tissue in the abdominal area and around certain organs.

Synthesis of Fatty Acids

Synthesis of fatty acids occurs in the cytosol. Enzymes exist as a complex - Fatty Acid Synthetase intermediates are covalently linked to acyl carrier protein. Synthesis begins with activation of acetyl CoA to malonyl CoA by addition of CO_2 .

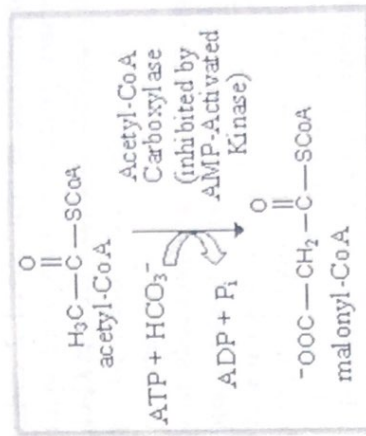
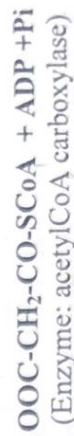


Figure 17: Formation of malonyl-CoA

Malonyl CoA is synthesized by the action of acetyl/CoA carboxylase (Biotin is a required cofactor).



The reaction is irreversible. Acetyl/CoA carboxylation is a rate-limiting step of FA biosynthesis. Acetyl/CoA carboxylase is under allosteric regulation. (Citrate is a positive effector and palmitoyl CoA is a negative effector).

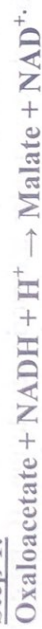
The fatty acid molecule is synthesized 2 carbons at a time. The primary product of fatty acid synthesis is palmitic acid (C-16). Fatty acids with longer C-chain and unsaturated fatty acids are obtained through modifications of palmitic acid. Fatty acid synthesis begins from the methyl end and proceeds toward the carboxylic acid end. Thus, C-16 and C-15 are added first and C-2 and C-1 are added last. Acetyl CoA generated from pyruvate by the action of pyruvate dehydrogenase, PDH and by β -oxidation of fatty acids is in the mitochondria. Acetyl CoA has to be transported from the mitochondria to the cytoplasm. The movement of acetyl-CoA to the cytoplasm is done via a shuttle system - The Citrate Shuttle.

The Citrate Shuttle

Reactions of the Citrate Shuttle

AcetylCoA reacts with oxaloacetate to form citrate; a **tricarboxylate translocase** transports citrate from mitochondria to cytosol. In the cytosol, citrate is cleaved back to oxaloacetate and acetylCoA; the reaction is catalyzed by ATP-citrate lyase and requires the hydrolysis of one molecule of ATP. Oxaloacetate is converted back to pyruvate for re-entry into mitochondria

Step 1.

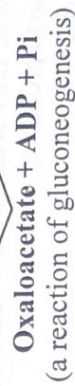


(Reverse of the TA cycle reaction; catalyzed by cytosolic malate dehydrogenase).

Step 2.



Pyruvate translocase transports pyruvate into mitochondria. Pyruvate is converted to oxaloacetate by pyruvate carboxylase with coupled hydrolysis of one ATP.



Net Reaction



Thus, transport of acetylCoA to cytosol requires expense of one ATP and conversion of one NADH to NADPH.

Catabolism of Lipids

Hydrolysis of Triacylglycerol

Triacylglycerol in the fat depot is hydrolyzed to free fatty acids and glycerol. The enzyme required for the hydrolysis, lipase will be activated though a cascade of reactions initiated by the action of a hormone such as epinephrine or glucagon to form cAMP. Insulin inhibits the formation of cAMP, hence suppress hydrolysis of triacylglycerols/fatty acids oxidation. (Presumably insulin makes glucose available for energy; fatty acids oxidation is therefore, not needed). Transport of free fatty acids from adipose tissue to the liver – the principal site of fatty acid oxidation.

Oxidation of fatty acid with the removal of 2 C-atom in each cycle to produce;

- FAD
- NADH
- Acetyl Co-A

The three products provide chemical energy for making ATP in the respiratory chain. Fatty acids and smaller fragments of fatty acids produced during oxidation can also be used in the heart and skeletal muscle for energy production; most of the energy needs of skeletal muscle at rest are met by intermediates from fatty acids catabolism and not from glucose. Both fatty acids and glycerol units from tri-acyl glycerol hydrolysis are available for energy production; the fatty acids are more important as energy source

Beta Oxidation Cycle

Fatty acid undergoes a process of degradation known as beta oxidation or **fatty acid spiral**. Fatty acid spiral involves a progressive shortening of the C-chain by removal of 2 C-atoms at a time. At the end of each turn an acyl-CoA is produced which has 2 C-atoms less than the original. The process is continued until the C-chain has been completely changed to acetyl Co-A. Each acetyl Co-A enters the CAC to be oxidized into CO₂ and H₂O.

Fatty Acid Spiral

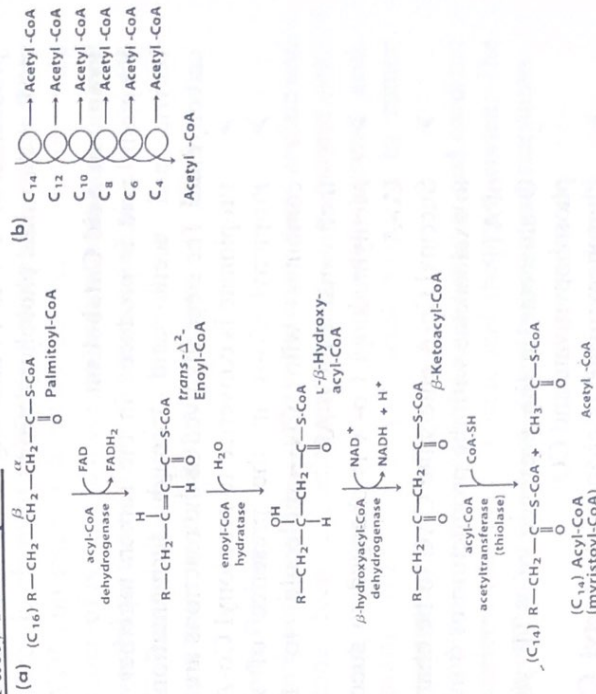


Figure 18: Fatty Acid Catabolism

Production of ATP through Fatty Acid Spiral

Each mole of acetyl Co-A will produce 12 moles of ATP from ADP via the CAC. The initial phosphorylation is necessary only once for each mole of fatty acid. More ATP is thus produced for the expenditure of the same amount of energy in the oxidation of along chain fatty acids than a short chain fatty acid. Oxidation of the 6-C stearic acid will produce 10 moles of ATP from reduced coenzymes arising during the production of 3 moles of acetyl Co-A. The 3 moles of acetyl Co-A will yield 36 moles of ATP from ADP via the CAC. The net production of ATP is 44 allowing for the use of 2 moles ATP in the initial phosphorylation.

Propionic Acid Catabolism

Propionic acid is produced in the rumen together with butyric and acetic acid through fermentation of carbohydrate. The steps involved in the reactions are;

- Propionate is converted to propionyl Co-A
- Propionyl Co-A in the presence of ATP combines with CO₂ molecule to form methylmalonyl Co-A
- Methylmalonyl Co-A is changed to succinyl Co-A
- Succinyl Co-A enters the CAC to be changed to oxaloacetate with the production of 6 moles of ATP
- Oxaloacetate in the presence of ATP yields phosphopyruvate and CO₂
- Phosphopyruvate is changed to acetyl Co-A that will be oxidized via the CAC

Yield of ATP from Propionic Acid Catabolism

A net production of 18 moles of ATP (6 + 12) from ADP per mole of propionate oxidized is obtained each yielding 12.5 Kcal of energy on hydrolysis. Normally, propionate produced in the rumen is transported to the liver and changed to glucose which is then used as a source of ATP. The yield of ATP is again 18 moles per mole of propionate oxidized.

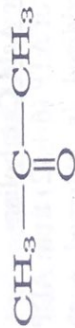
Catabolism of Glycerol

Glycerol is changed to glycerol phosphate using a mole of ATP and later to dihydroxyacetone phosphate in the presence of NAD⁺. Dihydroxy acetone phosphate is then converted to acetyl CoA to be oxidized to CO₂ via the CAC. The net gain of ATP from ADP using a mole of glycerol is 22 moles.

Ketone Bodies

Ketone bodies are β -hydroxyl butyrate, aceto-acetate and acetone. Ketone bodies are formed from butyric acid, one of the three volatile fatty acids (acetic acid, propionic acid and butyric acid) produced by rumen microorganisms.

Ketone Bodies are also formed in the liver and oxidized in skeletal and heart muscle and the renal cortex. The brain can adapt to use of ketone bodies under starvation.



Acetone



Acetoacetate



D-β-Hydroxybutyrate

Figure 19: Ketone Bodies

Ketosis is physiological condition when higher than normal concentrations of ketone bodies are found in the blood. Concentration of ketone bodies in well fed animals rarely exceeds 1 mg/dl.

Unit 15

Protein Metabolism

The Roles of Protein in Animal

Proteins make up the structural tissue for muscles and tendons, Proteins transport oxygen or hemoglobin. Proteins as enzymes catalyze all biochemical reactions as enzymes. Proteins as hormones regulate biochemical reactions. Proteins are involved in the process of growth, tissue replacement, and repair. Proteins in excess of body requirements are used to supply energy or build reserves of glucose, glycogen, or lipids.

Nitrogen Cycle

Recycling of carbon, oxygen and nitrogen occur in nature. Certain microorganisms possess the appropriate enzymes needed to convert elemental nitrogen from the air into ammonia, nitrate, and nitrites. (nitrogen fixation). The green plant uses the ammonia or nitrate as raw materials for the synthesis of amino acids and proteins. Animals in turn consume plants to obtain nitrogen for amino acids and proteins synthesis. The nitrogen cycle is completed when plant and animal residues are decayed by microorganisms back to nitrates, nitrites and finally nitrogen gas for the air.

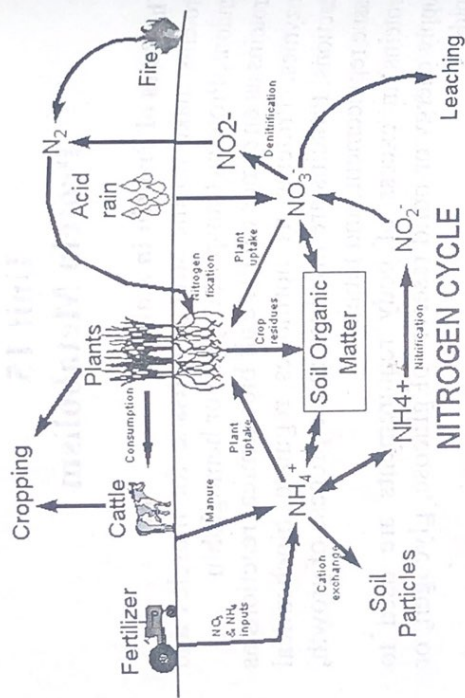


Figure 20

Nitrogen Pool

The "nitrogen or amino acid pool" is a grand mixture of amino acids available in the body. Nitrogen pool is derived from dietary sources or the degradation of protein. Proteins and amino acids are not stored in the body. Protein is constantly being synthesized or degraded. Liver and plasma proteins have a half-life of about 180 days while enzymes and hormones may be recycled in a matter of minutes or hours. Amino acids are catabolized to produce energy and ammonia. The excretion of the body also represents a drain on the nitrogen pool

Nitrogen Balance

A nitrogen balance is achieved when dietary nitrogen intake is balanced by the excretion of urea wastes. When nitrogen excretion is greater than the nitrogen content of the diet, the animal is said to be in negative nitrogen balance; it is usually an indication of tissue destruction. If the nitrogen excretion is less than the content of the diet, a positive nitrogen balance indicates the formation of protein; it is usually indicated in growth.

The Breakdown of Protein

Protein is made from amino acids (carbon, hydrogen, oxygen, nitrogen, and sulfur). Nitrogen, a basic component of amino acids accounts for 13 - 20% of the total mass of a protein molecule. The first step in protein metabolism is to break the protein molecule into constituent amino acids. Amino acids are absorbed into the blood stream. Amino acids are catabolized to remove the nitrogen or amino group from the amino acids; the process is called deamination. Deamination breaks the amino group down into ammonia and a carbon skeleton. Ammonia is converted to urea, filtered through the kidneys, and excreted in urine. The carbon skeleton—which is composed of carbon, hydrogen, and oxygen—is used either for protein synthesis, energy production (ATP), or glucose synthesis. Amino acids provide the major source of glucose for blood sugar maintenance only under conditions of intense exercise or metabolic starvation.

The Urea (Ornithine) Cycle

Urea is the major end product of nitrogen metabolism in mammals. A small amount of ammonia, the product of oxidative deamination reactions, is toxic and must be removed from the body. Ammonia is removed from an animal's body through its conversion to a less toxic urea. The urea cycle or the ornithine cycle describes the conversion reactions of ammonia into urea thus;

- One amine group comes from oxidative deamination of glutamic acid while the other amine group comes from aspartic acid.
- Aspartic acid is regenerated from fumaric acid produced by the urea cycle.
- The fumaric acid first undergoes reactions through a portion of the citric acid cycle to produce oxaloacetic acid which is then changed by transamination into aspartic acid

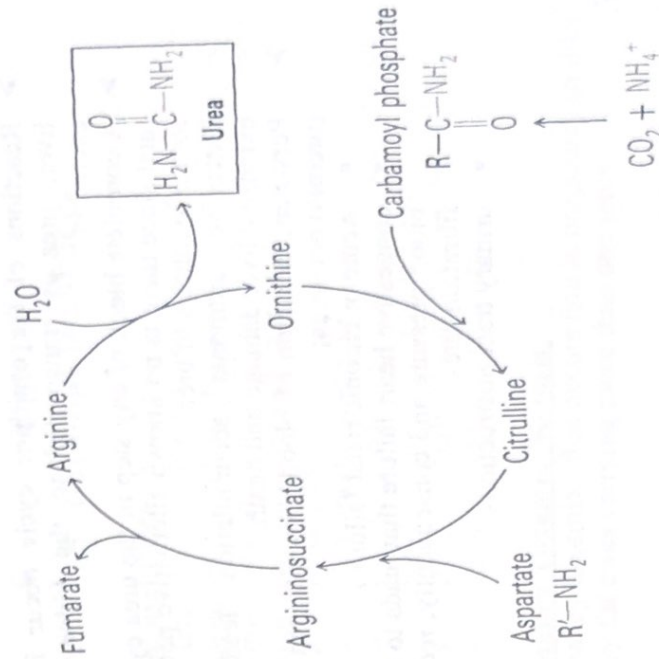


Figure 21: Ornithine (Urea) Cycle

Summary:

2 Ammonia + carbon dioxide + 3ATP



Urea + water + 3 ADP

- Reactions of the ornithine cycle occur in the liver; urea is transported to the kidneys for excretion
- A complete block of any step in the urea cycle is fatal since there is no known alternative pathway for the synthesis of urea.
- Extensive ammonia accumulation leads to extensive liver damage and death.
- Persistent elevation of blood urea nitrogen level (uremia) occurs in;
 - Acute or chronic renal failure.
 - congestive heart failure that leads to a low blood pressure and consequently, reduced filtration rates.
 - urinary tract obstructions

Unit16

Nutritional Disorders

Nutritional Diseases

Disorders resulting from a deficiency, an excess or an imbalance of nutrients, represent a major cause of economic loss in animal production business. Major causes of nutritional diseases in animals include;

- Inadequate feeding
- Nutrient imbalance
- Forced production (extreme rate of body weight gain or milk production)
- Poor soil/herbage nutrient concentration
- Confinement of the animals

Pregnancy Toxemia (Ketosis)

Pregnancy toxemia often occurs late in pregnancy in thin or very fat ewes carrying more than one fetus.

Acidosis

Acidosis or grain overload is a major form of feed poisoning in animals. Too much intake of grain can acidify the whole body system to cause severe indigestion and sometimes results in death

Dehydration

Dehydration is an excessive loss of water from the body or from an organ or body part. Dehydration may be caused by diarrhea, kidney diseases inadequate water supply or poor water quality.

Milk Fever

Milk fever often results from low blood calcium characterized by loss of appetite, grinding of the teeth, muscular tremors/paralysis and occasionally, death. Trembling, panting and convulsion are some of the symptoms observed in dogs and horses

Bloat

Bloat is common in ruminant livestock including cattle, sheep and goat. Bloat is can be treated by passing tube, abdominal wall puncture and drug administration

Laminitis (Founder)

Laminitis, an inflammation of the hoof wall is often caused by feeding too much grain which produces bacterial toxins. Loss of appetite and painful walk resulting from laminitis can be treated using laxatives stomach tube or surgery.

Mineral Deficiency Diseases

Anaemia

Anaemia in the livestock may be caused by an iron or copper deficiency or a high level of infestation with internal parasites. Animals suffering from anaemia may be identified by loss of appetite, emaciation, rough hair coat, pale membranes in the mouth and eyes. Anaemia is more prevent young, suckling animals as milk is a poor source of iron. Treatment of anaemia in animals can be effected by iron injection or improving access to iron rich sterile soil. Provision of balanced diet to the young animal soon after birth (less than 10 days) can prevent anaemia; preventive measures in swine also include;

- Use of Iron Dextran solution.
- Placing clean soil in farrowing stalls daily (time consuming!).
- Oral administration of Iron tablets or paste, daily

Milk Fever

Milk fever often observed in female animals (especially cows), shortly after parturition is caused by a low blood calcium concentration or too much calcium in the diet during the period. Symptoms of milk fever soon after parturition in high producing dairy cows include; loss of appetite, constipation, nervousness, followed by unconsciousness; the head is usually turned toward the shoulders. Milk fever is treatment with intravenous administration of calcium; it may be prevented by maintaining appropriate dietary Ca: P (2:1) or reducing dietary calcium level, 10-14 days to parturition.

Goiter

Inadequate supply of iodine in the form of thyroxine to the thyroid gland can cause goiter; plant compounds which interfere with absorption of iodine may also cause goiter. Goiter in animals is characterized by the swelling of the thyroid ("big neck"), reproductive failures, hairless newborn piglets, and weak foals.

Addition of iodized salt to diet will prevent goiter, a rare disease in the livestock with no effective treatment method.

Vitamin Deficiency Diseases **Osteomalacia (Rickets)**

Osteomalacia is caused by inadequate vitamin D or an incorrect ratio of calcium to phosphorus. Symptoms seen are lack of appetite, enlarged joints, stiffness of joints, weight loss, bowed legs. Treatment is limited once the animal shows signs of the disease; vitamin/mineral supplements occasionally relieve the condition.

Prevention consists of feeding balanced rations, proper fertilization of soils for feed crop production, adequate exposure of animals to sunlight.

Stiff - Lamb Disease (White Muscle Disease)

White muscle disease is caused by a deficiency of vitamin E or selenium or an imbalance of selenium and vitamin E. Symptoms of white muscle disease include; humped back, stiff-stilted movement.

White muscle disease occurs more frequently in young fast growing lambs. White muscle disease is treated with vitamin E/selenium injections and could be prevented by giving vitamin E/selenium injections at docking time and at 2 to 4 weeks of age.

Night Blindness (Xerophthlamia)

Night blinded in animals may be caused by a low intake of vitamin A.

Animals with Xerophthlamia have faulty vision at night, rough hair coat, severe diarrhea and a failure to row. Xerophthlamia is treated increasing diet vitamin A level and administering vitamin A injection. Animals are to be fed green pasture, yellow corn and other vitamin A -rich feeds to prevent night blindness. Mature animals can

store vitamin A in the liver to meet requirements for up to 6 months; young animal need a regular supply.

Toxicity Diseases

Toxicity diseases are by excessive intake or wrong combination of chemical compounds

Urinary Calculi

A high intake of potassium, a high calcium-low phosphorus ratio, or high dietary silica content may cause urinary calculi; Vitamin A deficiency often contributes to the condition. Urinary calculi usually cause frequent and painful urination. Urinary calculi occur only in male animals; treatment which is rarely successful may involve adding ammonium chloride to the diet or increasing diet salt level or surgery.

Measures to prevent urinary calculi in male animals include;

- increasing the dietary salt content
- delaying castration,
- avoiding high phosphorus or high calcium diets.

Selenium poisoning

Selenium poisoning is often caused by consumption of plants grown on soils with high selenium content or inappropriate use of selenium supplements. Symptoms of selenium poisoning include loss of hair from the tail in cattle, loss of the mane and tail in horses or loss of body hair in swine and lameness in severe case.

Selenium poisoning is prevented by pasture rotation, and avoiding soils with high selenium level; treatment is always ineffective

Nitrate Poisoning

Nitrate poisoning may result consumption of forages high in nitrates. Examples of crop plants with high nitrates levels are; Sudan grass, oat hay, corn stalks. Nitrates levels in plants increased when the plant is exposed to stressful conditions such as; drought, high temperature, excessive cloudy days, excess nitrogen from fertilizers, low sugar content, or after spraying with a weed killer. Surface runoff from ponds or irrigation in well fertilized areas may also increase nitrate concentration in plants. Nitrate poisoning results in increased pulse and respiration, diarrhea, frequent urination, and blue colored mucous membranes.

An accurate diagnosis of nitrate poisoning is by examining the blood which appears brown as haemoglobin changes to methemoglobin that cannot carry oxygen, making the animal slowly suffocating. Intravenous administration of methylene blue is known to be an effective treatment for nitrate poisoning which can be prevented by;

- feeding high levels of grains and molasses
- ensiling forages high in nitrates
- routine feed laboratory analysis to pre-determine nitrate content.

Metabolic Profiles of Major Animal Tissues/Organs

Brain

Neurons in the brain use only glucose as energy source. The brain needs a steady supply of glucose as on a small amount of glycogen is stored. The brain is able to oxidize ketone bodies during long fasts.

Liver

Maintenance of a fairly steady concentration of glucose in the blood is one of the liver's main functions. Liver regulates blood glucose level through gluconeogenesis and glycogen synthesis and degradation. Liver synthesizes ketone bodies when acetyl-CoA is plenty; it is also the site of urea synthesis.

Adipose tissue

Adipose tissue synthesizes fatty acids and stores them as triacylglycerols. Glucagon activates a hormone-sensitive lipase, which hydrolyzes triacylglycerols to yield glycerol and fatty acids; the products are released into the bloodstream in lipoproteins.

Muscle

The muscle uses glucose, fatty acids, ketone bodies and amino acids as energy source. Muscle also contains a reserve of creatine-phosphate, a compound with a high phosphate-transfer potential that is able to phosphorylate to ATP, thereby producing energy without using glucose. The amount of creatine in the muscle is enough to sustain about 3-4 seconds of exertion. The muscle uses glycolysis when creatine is exhausted - first anaerobically (it is much faster than the citric acid cycle). The muscle shifts to aerobic glycolysis when the

increased acidity slows down phosphor-frutokinase enough for the citric acid cycle to become non-rate-limiting.

Kidney

The kidney performs gluconeogenesis and release glucose into the bloodstream. Kidney is also responsible for the excretion of urea, electrolytes, etc. Kidney may take part with liver to eliminate excess nitrogen in condition of metabolic acidosis. Kidney glutaminase then cleaves glutamine in glutamate to NH_3 , which the kidney immediately excretes; the process allows nitrogen excretion without affecting blood bicarbonate levels.

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Trypto- phan	trp	W	$\begin{array}{c} \text{H O} \\ \parallel \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{O}^- \\ \\ \text{CH}_2-\text{CH}=\text{CH}-\text{Ar} \end{array}$	Neutral Slightly polar
Tyrosine	tyr	Y	$\begin{array}{c} \text{H O} \\ \parallel \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{O}^- \\ \\ \text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}=\text{CH}-\text{Ar} \end{array}$	Neutral Polar
Valine	Val	V	$\begin{array}{c} \text{H O} \\ \parallel \\ \text{H}_3\text{N}^+-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \\ \text{H}_3\text{C}-\text{CH}-\text{CH}_3 \end{array}$	

Properties of Amino Acids

Physical properties

Amino acids are quite soluble in water and have high melting points. They are amphoteric compounds (zwitter ions) having both acidic and basic properties. Amino acids exist either as uncharged molecules or as dipolar ions with opposite ionic charges; they act as buffers to resist changes in pH.

Decarboxylation

Amino acids undergo decarboxylation reaction to release the carboxyl group as CO_2 and form an amine

Deamination

Amino acids can be deaminated to produce carboxylic acid and ammonia

Esterification

The carboxyl group of an amino acid can be esterified with an alcohol to form soap and water

Oxidation

Amino group in an amino acid molecule can be oxidized to nitrogen; with a mild oxidizing agent such as ninhydrin, it will form ammonia. Ninhydrin reaction produces an intense blue colour with most amino acids; yellow colour is produced with proline and brown colour with asparagines.

Transamination

An amino acid can react with a keto acid to release its amino group and change the keto acid to a new amino acid

Indispensable Amino Acids

Plants and microorganisms synthesize proteins from simple nitrogenous compounds such as, nitrates. Animals unlike plants, cannot synthesize the amino group but they can form the carbon-skeleton of a number of amino acids. Certain amino acids may be formed in the animal's body through the process of Transamination while others are indispensable.

Indispensable or Essential Amino Acids are those amino acids an animal cannot synthesize by itself and must obtain from diets. They are; Valine, Arginine, Threonine, Tryptophan, Histidine, Isoleucine, Leucine, Lysine (Methionine, Phenylalanine. (VATT HILL (MP). Chicks would require glycine in addition to the ten amino acids

while pigs are able to synthesize arginine. Cystine has sparing effects on methionine

In Ruminants all the twenty amino acids can be synthesized by the microorganisms in the rumen; the rumen microbes can utilize ammonia (NH_3) in the presence of adequate energy, to synthesize amino acids they require. Non ruminant animals like swine, poultry, depend on dietary intake for the ten essential amino acids since there are no microbes to synthesize them. Rabbits, guinea pigs and horses harbor some microorganisms in the caecum that synthesize amino acids. Absorption of amino acids produced in the caecum is limited, unless the animals practice coprophagy regularly; Coprophagy in horses is only occasional.

Proteins

Proteins are macromolecular polymers of L- α -amino acids. All proteins contain C, H, O and N; most also contain sulphur and many have phosphorus in addition. Polypeptide structure of proteins contains more than 40 amino acid residues. Substances with less than 40 amino acids are simply referred to as polypeptides. Proteins are classified as either Simple protein which yields only amino acids on hydrolysis or Conjugated proteins which yield amino acids plus non-protein prosthetic groups.

Structures of Protein

Primary structure is the linear sequence of amino acid residues that make up the polypeptide chain. Secondary structure is the structure resulting from the H-bond interactions between amino acid residues fairly close to

one another. The structure may be regular to give the polypeptide chain a α -helix structure or an irregular coil. Protein tertiary structure describes the bending and folding of the polypeptide chain resulting from interactions between R- groups of amino acids that are relatively far apart. Tertiary structure describes biological activities of a protein. Quaternary structure of a protein results from interactions between separate polypeptide chains of a protein that contains more than one subunit or protomers. An example of quaternary structure is the oligomeric protein such as haemoglobin containing one α - chain protomer and two β - chain protomers.

Properties of Protein

Precipitation

Soluble proteins can be precipitated with salt solutions.

Amphoteric reactions

Proteins behave like amphoteric compounds due to the presence of $-\text{COOH}$ and $-\text{NH}_2$ groups on terminal and side chain amino acids.

Denaturation

Denaturation is a non proteolytic modification of the secondary and tertiary structures of a protein from its native state to a more distorted arrangement. A random structure of protein indicates complete denaturation. Protein denaturation changes the physical, chemical and biological properties of the protein

The denaturation may be reversible or irreversible. Proteins can be denatured by heat, acids or base. An 8 M urea is often used to bring about reversible denaturation of proteins.

Hydrolysis of Proteins

Proteins and polypeptides can be hydrolyzed with enzymes, acids or alkalis to yield the constituent amino acids and the non-protein units. A complete hydrolysis of protein may be effected with 6 N HCl at 100° C for 12-24 hours in a sealed vial. The temperature (100° C) would however, result in total denaturation of tryptophan and in partial loss of serine and threonine. Correction for the loss of tryptophan and serine can be made by withdrawing samples at different periods of the hydrolysis for analysis and extrapolating to the zero time.

Hydrolysis of proteins using 2-4 N NaOH for 4-8 hours at 100° C would cause some destruction of the S-containing amino acids and hydroxy amino acids; tryptophan would however remain unaffected. Some non-specific proteases have been prepared from bacteria and fungi. Enzymatic hydrolysis of protein is gentle and can be specific for a particular amino acid site.

Quantitative Determination of Protein - The Kjeldahl Method

The Kjeldahl method is very useful for determining protein in a crude mixture. A modification of the kjeldahl method could estimate protein levels in the range of 1-10 mg. The kjeldahl method involves:

1. About 2 g of the material to be analyzed (the sample) is digested with conc. H₂SO₄ in the presence of small amount of Cu²⁺, Se²⁺ or Hg²⁺ as catalyst
2. K₂SO₄ is added to the mixture in order to raise the B.P of K₂SO₄
3. The mixture is heated to oxidized the sample and convert protein N to (NH₄)₂SO₄
4. The digestion process is followed by addition of a strong base (40 % NaOH) to liberate ammonia from (NH₄)₂SO₄
5. Ammonia liberated is distilled, trapped in an acid (boric acid) and quantitatively determined by titration with 0.01 M HCl.

The results of the Kjeldahl method are usually expressed as crude protein; the % N in the sample is multiplied by a factor. A factor of 6.25 is often used which is based on the average content of N in many proteins. Since all organic forms of N would be converted to ammonia by the condition of the digestion, a preliminary separation of proteins from non-protein nitrogenous compounds in the sample may be carried out - to make the procedure specific for proteins. The Kjeldahl procedure is relatively time consuming. More rapid methods for estimating proteins in their relatively pure forms include; Biuret

method, Folin-Ciocalteus method & Lowry method (a modification of Folin method).

High Quality Protein

A protein sample can be either of high or low quality. A high quality protein contains all the ten essential amino acids in proper balance and quantities to satisfy the animal requirements. High quality proteins are must be included in diets for poultry, swine, and fish. Important sources of high quality proteins include; fish meal, dairy products; meat and bone meal.

A low-quality protein is lacking in one or more of the essential amino acids or contains all the essential amino acids in improper amounts. Two or more low quality proteins may be mixed to meet the amino acid requirement of an animal. Corn meal plus soybean meal mixture can meet the amino acid requirements of swine. Sources of low quality proteins include soybean meal, cotton seed meal,

Unit 6

Nucleic Acids

Nucleic Acids

Nucleic acids are polynucleotides of very high molecular weights. Nucleic acids carry genetic information; they provide the means by which genetic information is utilized in the synthesis of proteins.

Hydrolysis of Nucleic Acids

Nucleic acids upon hydrolysis would yield;

- Basic nitrogenous compound
- Pentose sugar – ribose, deoxyribose
- Phosphoric acid

Formation of nucleoside

A nucleoside is formed between a purine or pyrimidine and a sugar molecule e.g. adenine + ribose = adenosine.

Esterification

Esterification of nucleoside with phosphoric acid will form a nucleotide e.g. adenosine + P_i = adenosine monophosphate, AMP. A further esterification reaction will produce ADP, ATP nucleotides. Several nucleotides form a nucleic acid.

The two groups of nucleic acids

Ribonucleic acid, RNA

RNA has three main types; mRNA (messenger RNA), tRNA (transfer RNA) and rRNA (ribosomal RNA). It consists of a single strand; it has ribose sugar; it has uracil as the pyrimidine base.

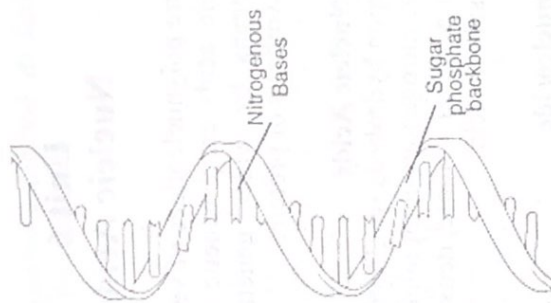


Figure 10: RNA Structure

Deoxy-ribonucleic acid, DNA
 DNA consists of double strands. It has a deoxy ribose, a thymine as the pyrimidine base

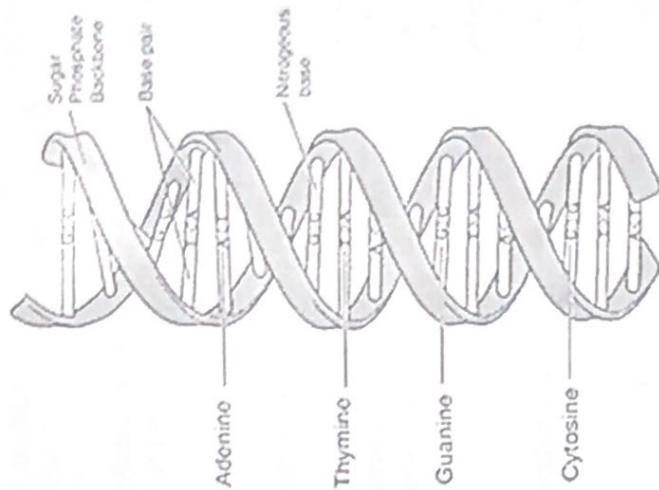


Figure 11: DNA Structure

Unit 7

Enzymes

Enzymes

Enzymes are proteins that function as organic catalysts. Enzymes accelerate the rates of chemical reactions in the body without being consumed in the reactions. Enzymes are grouped into six major classes;

1. Oxido-reductases—enzymes that catalyze the transfer of H, O- or electrons from one molecule to another.

- -CHOH
- -COO-
- -CH=CH
- -CH-NH₂
- -CH-NH-
- NADH, NADPH

Examples: dehydrogenases; oxidases; peroxidases; catalases; oxygenases; and hydroxylases.

2. Transferases – enzymes involved in the transfer of functional groups from one molecule to another

- 2.1 -Carbon
- 2.2 - aldehyde and ketone
- 2.3 - acyl
- 2.4 - glycosyl
- 2.5 -PO₄
- 2.6 - sulphur containing

Examples: transaldolases and transketolases; acyl, glucosyl and phosphoryltransferases; kinases

3. Hydrolases – enzymes that catalyze hydrolytic cleavage (hydrolysis reactions)

- 3.1 - esters
- 3.2 - glycosidic bond
- 3.3 - peptide bond
- 3.4 - other C-N
- 3.5 - acid anhydrides

Examples: glycosidases; peptidases; phosphatases; thiolases; phospholipases; deaminases; ribonucleases.

4. Lyases – enzymes that catalyze non-hydrolytic decompositions such as decarboxylation and deamination

- 4.1 - C=C-

Examples: Idolases; hydratases; dehydratases; synthases

5. Isomerases –enzymes that catalyze intra-molecular rearrangements

- 5.1 -racemase

Examples: racemases; isomerases

6. Ligases – enzymes catalyze bond formation, using from high-energy compounds such as ATP.

- 6.1 -C-O-
- 6.2 -C-S-
- 6.3 -C-N-
- 6.4 -C-C-

Example: synthetase

Enzymes Nomenclature

The first part of the name of an enzyme indicates the substrate for the enzyme while the second part indicates the type of reaction that is carried out by the enzyme. The class, subclass and sub-subclass of the particular enzyme are indicated by numbers. Consider for example,

L- α -Glutamate β -Carboxylase 4.1.1.15

L- Lactate:NAD⁺ oxidoreductase 1.1.1.27

(1st – main class; 2nd – subclass; 3rd – subclass; 4th identifies the enzyme)

Properties of Enzymes

- Enzymes are complex protein molecules of high molecular weights
- Enzymes exist in distinct compartments – cytoplasm, mitochondria
- Enzymes affect only the kinetic of a chemical reaction by lowering the activation energy barrier for the reaction
- Enzymes cannot make a thermodynamically unfeasible reaction take place
- Enzymes can increase the velocity of chemical reactions by 10^3 - 10^6 folds e.g. conversion of peroxide to water & H₂ increased by 10^6
- Enzyme catalyzed reactions are theoretically reversible and could reach equilibrium

- The reactions catalyzed by enzymes are largely unidirectional and do not normally reach equilibrium since their products are continuously being removed
- The reactions catalyzed by enzymes exist in a steady state in which concentrations of reactants remain constant.
- The reactions catalyzed by enzymes would speed up under demand or slow down when products are not removed rapidly enough.
- Enzymes affect rates of both forward & backward reactions equally
- Many enzymes need low molecular weight, non-peptide groups called co-enzymes to function effectively.
- Co-enzymes may be a prosthetic group which are permanently attached to the enzyme e.g. Fe²⁺ in Cytochromes or which may be released after the reaction e.g. Nicotinamide Adenine Dinucleotide, NAD⁺
- Some enzymes require the presence of activators in the form of metal ions e.g. Mn⁺
- Some enzymes are present in inactive forms which are converted to the active enzymes at the time and place of usage
- Trypsinogen is synthesized in the pancreas, transported to the small intestine where it is changed to the active digestive enzyme, Trypsin
- Enzymes exhibit substrate specificity which may be absolute as in urea for urease or relative as in trypsin (low) and chymotrypsin (high).

- Enzymes are denatured by extremes of temperature and pH.

Mechanisms of Actions of Enzymes

There is no general mechanism that can be used to explain the actions of all enzymes. The Enzyme-Substrate Complex and the Lock-and-key hypotheses are the two mechanisms generally accepted.

Enzyme-Substrate Complex hypothesis

Enzyme and substrate combine to form enzyme-substrate complex. The substrate reacts while still bound to the enzyme to form enzyme-product complex. Enzyme-product complex splits into enzyme and product molecules.

Enzyme + Substrate $\leftrightarrow$ Enzyme-substrate complex

Enzyme + Products $\leftrightarrow$ Enzyme-product complex

Lock-and-Key Hypothesis

An enzyme has a specific place called active site on the enzyme. Substrate molecule becomes attached to the active site of the enzyme. The shape of the active site and position of the different chemical groups within it ensure that only substrates with complementary structure can combine with the enzyme

Factors Affecting Enzyme Activity

Temperature

The rate of enzyme-catalyzed reaction is increased by raising the temperature. A 10° C increase/decrease in temperature could double/half the rate of a reaction. Above certain limit of increase in temperature (50°C) the protein nature of the enzyme could be denatured. Every enzyme has an optimum temperature at which it will act most effectively

pH

The hydrogen ions concentration of the reaction medium affects the activity of an enzyme. Most enzymes are most effective at a pH range of 6-7 (the pH of the cell)

Substrate Concentration

Increasing substrate concentration in the presence of excess enzymes can cause an increase in the rate of the enzyme-catalyzed reaction. The molar concentration of substrate at which half the active sites of the enzyme are occupied by substrate and the rate of reaction is reduced by half is represented by K_m – the Michaelis-Menten constant.

Enzyme Concentration

Increasing enzyme concentration where the substrate is in excess would cause an increase in the rate of enzyme-catalyzed reaction, provided other limiting factors such as co-enzymes are present.

Enzyme Inhibition

The catalytic action of an enzyme may be inhibited by substances which prevent the formation of a normal enzyme-substrate complex or disrupt the 'lock and key' interaction. An enzyme inhibitor is described as either competitive or non-competitive.

Competitive (Reversible) Enzyme Inhibition

A competitive enzyme inhibitor is similar to the substrate in its chemical structure. The inhibitor is able to combine with the enzyme to form an enzyme-inhibitor complex at the active site. It competes with the substrate for the active sites of the enzyme to reduce the formation of enzyme-substrate complex. Substrate molecules combine at the few available active sites on enzyme-inhibitor complex to form enzyme-inhibitor-substrate complex.

The three molecules dissociate to **enzyme, inhibitor** and **product** but the rate of product formation would have been reduced considerably. For instance, malonic acid inhibits the oxidation of succinic acid by succinic dehydrogenase. Para-amino benzoic acid also inhibits sulphanilamide

Non-competitive (Irreversible) Enzyme Inhibition

A non-competitive inhibitor does not have a similar structure with the substrate and therefore, it does not compete with the substrate for the active sites. The inhibitor is such that will alter the enzyme molecule and destroy the active site for the substrate molecule.

Examples of non-competitive inhibitors are poisons such as cyanide and heavy metals (Hg, Ag)

Negative Feedback Inhibition

Negative feedback inhibition occurs when the product of a chemical reaction serves to inhibit further activity of an enzyme. Negative feedback inhibition is important in the control of biochemical reactions.

Unit 8 Vitamins

❖ Vitamins (Vital amines)

Vitamins are organic compounds which are required in very small amounts for growth and maintenance of life. Vitamins cannot be metabolized for energy production but are involved in metabolic pathways that produce energy. They are usually stored in protective layer of wax or gelatin as many vitamins are readily destroyed by oxidation in the presence of heat, light or metal ions. Pro-vitamins or vitamins precursors are substances such as carotene that can undergo chemical changes in the body to function as vitamins. Adequate intakes of vitamins can improve cellular health and enhance quality of animal products. For instance, vitamin A improves the health status of the mammary gland in dairy cows; vitamin D enhances strength of egg shell in poultry birds while vitamin E extends the shelf life of meat.

Deficiency of vitamins in animals can manifest in;

- Scouring
- low resistance to bacterial infection
- stiffness of joints and uncoordinated movements
- lesions around the eyes, dull watery eyes and night blindness
- poor sperm quality
- reduced fertility
- shortened period of gestation, a high incidence of retained placentas, stillbirths and abortions in pregnant animals

Hyper Vitaminosis is a pathological condition resulting from overdose of vitamins. Over supplementation of

diets with vitamins may result into hypervitaminosis in farm animals. An over dose of vitamin A may cause poor growth, diarrhea or death. Excessive intake of Vitamin D may lead to high blood calcium salts in arteries and organs while doses of menadione (VitaminK₃) often results in poor growth and anaemia

Water Soluble and Fat Soluble Vitamins

Vitamins are described as either water soluble (Vitamin B-complex) or fat soluble (Vitamin A, D, E, and K). Water soluble vitamins function primarily as enzyme cofactors in metabolism. They include;

Vitaminin B₁ (Thiamine)

Thiamine consists of a substituted pyrimidine joined to a thiazole by a methylene ring. The active form of thiamine in metabolism is thiamin pyrophosphate, TPP. Activation of thiamine to thiamine pyrophosphate is catalyzed by a specific enzyme- thiamine diphosphotransferase- in the brain and liver. Thiamine pyrophosphate serves as cofactor for;

- pyruvate dehydrogenase PDH
- α-ketoglutarate dehydrogenase αKGDH
- branched-chain ketoacid dehydrogenase BCKDH –for metabolism of branched chain amino acids (leucine, isoleucine and valine)
- transketolase catalyzed reactions of the pentose phosphate pathway

Deficiency symptoms of thiamine include; constipation, suppression of appetite, nausea and fatigue. Thiamine deficiency in animals results from low energy

production, reduced ability to carry out biosynthetic reactions or synthesized nucleotides.

Vitamin B₂ (Riboflavin)

Riboflavin is used to produce flavin mononucleotide, FMN and flavin adenine dinucleotide FAD as cofactors for the flavoprotein enzymes. (succinate dehydrogenase and xanthine oxidase). Riboflavin decomposes when exposed to visible light. Symptoms of riboflavin deficiency include;

- itching and burning eyes
- angular stomatitis
- bloodshot eyes, glossitis (inflammation of the tongue)
- flaking skin
- photophobia (excessive light sensitivity).

Vitamin B₃ (Niacin)

Nicotinic acid or nicotinamide can serve as the dietary source of vitamin B₃. The two active forms of vitamin B₃ in for which niacin is a precursor are;

- nicotinamide adenine dinucleotide, NAD⁺
- nicotinamide adenine dinucleotide phosphate, NADP⁺.
- NAD⁺ and NADP⁺ serve as cofactors for several dehydrogenase enzymes (e.g. lactate dehydrogenase and malate dehydrogenase)
- niacin deficiency like deficiency of tryptophan can manifest as an inflammation of the tongue (glossitis), dermatitis, diarrhea, and weight loss

Vitamin B₅ (Pantothenic Acid)

Pantothenic acid is synthesized from β-alanine and pantoic acid. The acid is required for synthesis of coenzyme A and for metabolism of carbohydrate, fat and protein. Symptoms of pantothenic acid deficiency include; skin abnormalities, stunted growth, restlessness and muscle cramps.

Vitamin B₆ (Pyridoxal Phosphate)

Inactive forms of vitamin B₆ are pyridoxal, pyridoxamine and pyridoxine. Deficiency symptoms of vitamin B₆ include; nervousness, insomnia, loss of muscular control, muscular weakness anemia, loss of hair, and water retention.

Vitamin B₁₂ (Cobalamin)

Vitamin B₁₂ consists of a complex tetrapyrrole ring structure with a cobalt ion in the center. Vitamin B₁₂ is synthesized exclusively by microorganisms; the liver stores vitamins. Two main metabolic processes in the body that require vitamin B₁₂ are the;

- catabolism of fatty acids with an odd number of carbon atoms and the amino acids valine, isoleucine and threonine
- conversion of homocysteine to methionine
conversion of homocysteine to methionine

Deficiency of vitamin B₁₂ can manifest in neurological complications resulting from a progressive demyelination of nerve cells, cardiovascular dysfunction from elevated level homocysteine in the blood and megaloblastic anaemia caused by inability of the stomach to produce intrinsic factor, required for

absorption of vitamin B₁₂. Deficiency of vitamin B₁₂ occurs, only when cobalt is lacking. All the B vitamins and vitamin K, can be synthesized by the microorganisms in the rumen

Folic acid

Folic acid is a conjugated molecule made up of pterotic acid (a pteridine ring structure and para-aminobenzoic acid, PABA) with glutamic acid. Animal cannot synthesize PABA nor attach glutamate residues to pterotic acid. Symptoms of folic acid deficiency include macrocytic anaemia due to an inability to synthesize DNA during erythrocyte maturation.

Vitamin C (Ascorbic Acid)

Ascorbic acid is more synthesized from glucose through the uronic acid pathway. Primates lack the enzyme L-gulonolactone oxidase required for the conversion of gulonolactone to ascorbic acid; Swine can synthesize vitamins C. Ascorbic acid functions as a reducing agent in metabolic reactions; it is the cofactor for Cu⁺-dependent monooxygenases; Fe²⁺-dependent dioxygenases; cytochromes a and c

Ascorbic acid as a cofactor in the hydroxylation of proline residues in the structure of collagen is essential in wound healing, bone remodeling and maintenance of normal connective tissues. It is also an antioxidant through roles as a reducing agent. Metabolic reactions that require ascorbic acid as a cofactor include catabolism of tyrosine, synthesis of epinephrine from tyrosine and synthesis of bile acids. Scurvy, a major symptom of vitamin C deficiency in animals is

characterized by; muscle fatigue soft swollen gums and haemorrhage due to modifications of collagen. Vitamin C is easily destroyed by light, air, and heat.

Fat Soluble Vitamins

Vitamin A (Retinol)

Biologically active compounds that function as vitamin A are retinol, retinal (retinaldehyde) and retinoic acid. Beta-carotene is the precursor of the three vitamin A active compounds. The two primary functions of vitamin A in the animal body are;

- Maintenance of the epithelium
- Regeneration of the light sensitive visual purple (rhodopsin) essential for vision in low illumination

Feed sources of vitamin A include, yellow corn, green leafy hay, and pasture; all green feeds are rich in both carotene and vitamin C. Storage of green plants over a long period however, can reduce the carotene contents considerably. Inclusion of vitamin A in premixes for animals on dry non-green grass hay, crop residues or silage is essential; vitamin A injection can also be administered. Vitamin A is the only vitamin in premixes that is not guaranteed because it is prone to oxidation.

Vitamin D(calciferol)

Vitamin D occurs in plant material in the form of a provitamin which is converted in the animal body to vitamin D when exposed to sunlight. Vitamin D is involved in the absorption and metabolism of calcium in the animal's body. Symptoms of vitamin D deficiency which are similar to those of calcium or phosphorus

deficiencies include ricket in the young animals and osteomalacia in the adult. Rickets is the development of soft bone resulting from improper mineralization development while osteomalacia is an increase in bone softness and susceptibility to fractures due to demineralization.

Vitamin D deficiency can be prevented by adequately exposing animals to sunlight, dietary supplementation with cod-liver oil and increasing level of sun-cured hay and good pasture in diets for ruminants.

Vitamin E (Tocopherols)

Vitamin E is a mixture of several related compounds known as tocopherols and tocotrienols. The tocopherols which also exist as α -, β -, γ -, and δ -tocopherols have free radical scavenging activities. Vitamin E is a metabolic antioxidant; it stimulates the immune response, to improve the resistance of the body to diseases. The antioxidant functions may be performed by some other antioxidants such as selenium.

Muscular dystrophies (myopathies or white muscle disease) in cattle can be prevented by administering traces of either selenium or vitamin E. Symptoms of vitamin deficiency are rare in farm animals except when the diets is also deficient in selenium

Vitamin K

Vitamin K is found naturally as phyloquinone (vitamin K₁) in green vegetables or menaquinone (vitamin K₂) produced by microorganisms along the digestive tract. The synthetic form, menadione is vitamin K₃. Vitamin K is absorbed from the intestine as part of chylomicrons

only in the presence of bile. Deficiency of vitamin K in farm animal is rare but may occur in fat malabsorptive disease conditions and following defaunation in a prolonged use of antibiotics. Newborn animals require adequate dietary intake of vitamin K before intestine microorganisms are established

Protection of Vitamins

Vitamins are easily destroyed by heat. They are often protected from oxidation by dispersing them in protective layers such as wax and gelatin. Antioxidants such as Butylated hydroxy toluene, BHT are usually added to commercial vitamin preparations.

Unit 9 Minerals

Mineral Salts

Mineral salts are compounds of a metal with a non-metal or a non-metallic radical. The constituent anions and cations in salts released in the body fluids. Most of the naturally occurring minerals are found in animals' tissues but not all of them have essential functions.

An essential mineral is one which has a metabolic role. Essentiality of a mineral is demonstrated by feeding a purified diet lacking in the mineral to animals. The element will be considered essential if deficiency symptoms develop from the intake of the purified diet and the symptoms are corrected upon adding the mineral back to the diet. Some minerals are required in fairly large amounts while some others are required in small quantities.

Minerals that are known to be essential and are required in large amounts include; calcium, phosphorous, sodium, magnesium and sulphur. Essential minerals that are required in small quantities include; Iron, selenium, copper, zinc, manganese, cobalt and fluorine. In addition, minerals such as silicon, vanadium, tin and nickel are considered to be essential trace minerals in certain livestock species. The quantity in which a mineral is required however, gives no indication of its relative importance to the animal.

Sources of Minerals to livestock

The earth crust is the ultimate source of minerals to plants and animals. Minerals present in soil are ingested by animals through feeds, drinking water, mineral supplements as well as soil, air or dust contamination. Animal feeds are prepared from plants and animal products and by products. Animal protein supplements often used in feed formulation are also good sources of minerals. Drinking water may contribute about 40 % sodium chloride, 7-30 % calcium and 20-40 % sulphur daily requirements of cattle. Contamination of herbage plants with dust and soil can also contribute a high percentage of the trace mineral requirements. Mineral supplements are often provided in the forms pulverized bone/shell, inorganic salts, licks, injectable preparations and water augmentation to correct inadequacy in minerals intake as a result of changes in environment or physiological state of the animal.

The Roles of Minerals in Animals

Most of the essential minerals have specific physiological, biochemical or structural roles in the animal's body. Functions of minerals in animals can be broadly classified into three;

- Structural components of body organs (Ca, P, Mg, F, Si in bones & teeth; P and S in muscle proteins)
- Regulation of body fluids – minerals can be constituents of body fluids and tissues where they exist as electrolytes to maintain proper acid-base balance, osmotic pressure, membrane permeability, & tissue irritability (Na, K, Cl, Ca

and Mg in blood, gastric juice and cerebrospinal fluids)

- Components of metallo-enzymes and hormones (Fe in cytochromes, Cu in oxidizes, Se in glutathione peroxidase)
- Cobalt and iodine have well defined functional role in the body (Cobalt is a structural component of Vitamin B₁₂; iodine is mainly a component of thyroxine structure)

Minerals maintain their structure in every environment as they cannot be destroyed.

Acid-Base Balance

An Acid is a compound which dissociates to produce hydrogen ions. The level of acidity is often expressed as pH – the negative logarithm to the base 10 of the H-ions concentration in moles per dm³.

$$\text{pH} = -\log [\text{H}^+]$$

A Base is a compound which combines with hydrogen ions produced by acid following dissociation. Animal cells and tissues can only tolerate a narrow change in acid or base concentration. Chemical reactions in the body tend to upset the desired neutral state of the cells by producing or utilizing hydrogen-ions. Certain chemical substances called Buffers resist any sudden or wide changes in body pH

Buffers include phosphates, bicarbonates, proteins (e.g. Hb)



Unit 10

Digestion of Feeds

The Body Physiological Systems

The animal's body is divisible into different f units called the body systems on the basis of physiological functions. Major body systems are the Skeletal-, Muscular-, Circulatory-, Respiratory-, Nervous-, Urinary-, Endocrine-, Reproductive-, Mammary- and Digestive systems. The various parts of an animal body that process feed macromolecules into smaller substances for absorption into body cells constitute the Digestive System.

The Gastro Intestinal Tract

The digestive tract also called the gastrointestinal tract of an animal body is designed to convert nutrients in feeds in to a form that can be absorbed and utilized by the body. The processing of feeds along the digestive tract involves digestion, absorption and wastes elimination. Digestion breaks down feeds/feedstuffs into absorbable form while absorption facilitates the passage of nutrients across the cellular lining of the digestive tract. Undigested portions of feed and waste products are removed from the body through the process of elimination.

Depending on the species, digestion includes processes such as;

- mastication (includes cud-chewing)
- chemical actions (HCl in the stomach)
- glandular secretions (enzymes to cleave chemical bonds)

- microbial action (ferment and digest feed)
- The type of feed suitable for an animal species is determined by the structure of its digestive tract which can one these;
- Herbivores, in animals that eat plant materials
 - Carnivores (facultative or strict) in animals that eat other animals
 - Omnivores in animals that eat both plant and animal materials
 - Insectivores, in animals that eat insects
 - Frugivores in animas that eat insects. (not common in domestic animal species)
 - Major structural divisions of the digestive tract are; mouth, pharnx, oesophagus, stomach, small intestine, large intestine

The Mouth

The mouth of an animal chews (grinds) feed and mixes feed with saliva. The act of chewing is not carried out in all animal species; the beak in bird is used only to reduce feed particle size. The teeth of carnivores also are adapted for holding, tearing and crushing (bone) but not for chewing

Saliva

The major roles of saliva in feed digestion are;

- moisten food, help form into bolus
- lubricates mouth, aids in taste mechanisms
- carrier for buffers and digestive enzymes,
- primarily amylase to begin breakdown of starches

The saliva is secreted into the mouth by three pairs of salivary glands:

- the parotids, (in front of each ear)
- the submandibular/submaxillary (on each side of the lower jaw)
- the sublingual (underneath the tongue).

Saliva is about 99 % (water); the other 1 % components include:

- Bicarbonate - neutralizes acids
- mucin - moistens the feed and the oral cavity for easy passage of feed down the esophagus
- antibodies defend against bacteria entering the mouth
- lysozyme, inhibits the growth of bacteria and prevents tooth decay

Salivary amylase is not found in horse, dog or cat. The pH of pig's saliva (7.3) is only slightly above the optimal pH amylase activity. Monogastric animals can survive without salivary glands; the ruminants cannot.

The Esophagus

Esophagus is a cartilaginous tube through ingested feed is passed from the mouth to the stomach. The cartilage is surrounded by muscular lining, controlled by central nervous system. In some animal species, passage of feeds only occurs in one direction; the horses are not capable of regurgitation or vomiting.

In ruminants will boluses of feeds regurgitated for re-chewing in a physiological process called rumination; some wild canines also keep meat in the stomach, to be regurgitated for the young back at the den. In most other

animal species, reverse movement of feeds is adapted only for emergency situations

The Stomach

The exterior surface of the stomach can be divided into three regions which are the;

- cardiac (entrance),
- fundus
- pylorus (terminus),

The cardiac and pylorus are sphincters that control the passage of feed through the stomach.

The inner surface of the stomach is increased in area by an in folding of the epithelium; it has four distinct regions;

- Non glandular region - an extension of the oesophagus; it has no secretory tissues

- Cardiac region which is lined with epithelial cells. It secretes mucin (a gel-forming glycoprotein which lines the stomach and protects the walls from being digested)

- Fundic region - has three types of cells;
 - parietal (oxyntic) cells, secrete HCl
 - neck chief cells, secrete mucin (glycoprotein and fucolipid mucus)
 - body chief cells, secrete pepsinogen, rennin, lipase

- Pyloric region - contains additional neck chief- and body chief- cells.

Pepsinogen is converted to pepsin (a protease) in the presence of HCl. Rennin is a milk curdling enzyme found only in young mammals; it can be used in cheese-making. Lipase breaks down chemical bonds in fat molecules. The gastric juice consists of water, pepsinogens, inorganic salts, mucus, hydrochloric acid and the intrinsic factor important for efficient absorption of vitamin B₁₂.

Secretion of gastric juice is stimulated by;

- the sight and smell of feed via the vagus nerve (cephalic phase)
- chemical sensors and distension of the stomach (gastric phase)
- neural and hormonal sensors due to the presence of feed in the duodenum

The stomach is sometimes referred to as glandular stomach because it is lined with secretory cells. Stomach is the first part in digestive tracts of animals where significant species differences occur. The digested feed from the stomach is referred to as chyme.

The Small Intestine

Small intestine is the primary site for enzymatic digestion. It consists of three parts; duodenum, jejunum, ileum. The partially digested feed (Chyme) from the stomach is mixed with secretions from the duodenum, liver and pancreas at the duodenum area of the small intestine. Duodenal (brunner's) glands produce alkaline secretion that acts as lubricant and protects duodenal wall from HCl corrosion. Secretions from pancreas and duodenum contain additional enzymes to digest nutrients. In addition bile is delivered through the bile

duct from the liver. The bile is stored in the gall bladder (except in horses, in which only continuous bile secretion is observed). Bile contains the sodium and potassium salts of bile acids, (glycocholic and taurocholic acids), phospholipids, bile pigments (biliverdin and bilirubin - end products of haem catabolism), cholesterol and mucin. The pancreas has both endocrine (production of insulin from islet of Langerhans) and exocrine (production of digestive enzyme from acinar cell, water and electrolyte) functions. Jejunum and ileum are primary sites for absorption of simple carbohydrates, minerals, fats and proteins.

The Large Intestine

Large intestine is composed of seven segments; 1) caecum, 2) ascending colon, 3) transverse colon, 4) descending colon, 5) sigmoid colon, 6) rectum and 7) anal canal

The relative size of each segment is dependent on the animal species and the type of diet it consumed. Rabbits and horse have large caecum while swine have small caecum.

The large intestine is important for retrieval of nutrients, electrolytes and water in the digesta. Absorption of nutrients (though of limited proteins and vitamins) occurs in caecum and colon. Coprophagy is practiced by rabbits and some other animal species to recycle nutrients and eliminate the need for some vitamins. Absorption of water occurs throughout the digestive tract but primarily in the colon. Faeces, voided via the anus consist of water, undigested feed, digestive secretions,

epithelial cells, inorganic salts, bacteria and products of microbial decomposition. The principal hormones involved in feed digestion are; gastrin, secretin, cholecystokinin and gastric inhibitory peptide

The Process of Digestion

Digestion is the process by which an animal breakdown large organic compounds components of a feed into simple, more soluble compounds that can pass through the mucous membrane of the alimentary canal into the blood and lymph. The processes of digestion consists of a series of mechanical mastication, muscular contractions), chemical (enzymatic, acid alkaline reactions) and microbial activities (bacteria, protozoa fungi). Digestive systems of animals are divided into two main categories; 1) Monogastric Digestive Systems and 2) Ruminant Digestive Systems

Digestion in Monogastrics

Monogastric animals also referred to as nonruminants, are animals with relatively small, simple, one-compartment stomachs containing limited microorganisms. Monogastrics are adapted to concentrate feeds; they cannot process high-fiber rations. Monogastric animals can be divided into 3 main groups;

- Monogastrics with a functional caecum, e.g. rabbits, guinea pigs, and horses. The presence of functional caecum can increase an animal's ability to digest roughage.

- Monogastrics with a nonfunctional caecum. e.g. swine. A non-functional caecum limits the ability to digest roughage.
- Avian digestive system has special organs (crop, gizzard) that soften, crush, and grind feed. An example of avian is the poultry (e.g. chickens, turkeys).

Major steps in digestion of feeds by monogastrics with or without functional caecum include;

- Feed brought to the mouth is chewed and mixed with saliva.
- The feed is moved down the esophagus to the stomach for proper churning and mixing with digestive juices.
- Digested feed is passed into the small intestine for absorption of nutrients
- Unabsorbed feed components left the small intestine, to the caecum.
- Additional digestion and absorption is carried in the caecum in animals with functional caecum,
- Undigested portion of the feed is moved into the large intestine, where absorption of water produced feces.
- The feces is stored in the rectum until it is expelled through the anus.

In avian species the stomach is replaced by crop, proventriculus and gizzard. The crop is a temporary storage site while gizzard, with its tough, muscular lining grinds up feed in lieu of chewing; proventriculus produces gastric secretions like the simple stomach. Feed in the mouth is passed immediately

through the esophagus to the crop for soaking and storage. The feed is moved from the crop to the true stomach (proventriculus) for mixing with digestive juices. The partially digested feed is further crushed and ground in the gizzard before it is passed through the small intestine, caecum into the large intestines for nutrients and water absorption and fecal formation. The feces is expelled through the vent

Digestion in Ruminants

Ruminants are animals that have stomachs with more than one compartment. The four compartments of the stomach in ruminants are the rumen, reticulum, omasum, and abomasums. The omasum is not very essential to the ruminants as it not present in pseudo-ruminant such as the camelids. Rumen is the largest stomach compartment while abomasum is the true stomach containing digestive enzymes. Ruminants have the ability to process and utilize high-fiber diets due to the presence of a large population of microorganisms in the rumen. The rumen is non-functional in young ruminants until the age of 8 or weeks.

An esophageal groove extends from cardiac to omasum and bypasses the rumen and reticulum in the young ruminant. The groove ensures the delivery of milk directly into omasum and abomasums as the presence of milk in the mouth initiates the closure of the esophageal groove. Esophageal groove is opened at the moment the young ruminant consumes forage and grain to deliver the feeds for fermentation into the rumen. The ability of a calf to close the esophageal groove is lost by the age of 2 years.

The essential steps in the process of feed digestion by the ruminant digestive systems are;

- Feed is chewed in large volume of saliva and made into bolus to ease swallowing
- Feed bolus is passed through the esophagus into the rumen, for microbial degradation
- A portion of the feed is forced from the rumen back into the mouth to be re-chewed and re-swallowed.
- The re-chewed feed is returned to the rumen and reticulum for further storage and further microbial degradation
- Activities of microorganisms result in anaerobic fermentation of feed and other organic substances
- By-products of fermentation in the rumen (carbon dioxide and methane) are eliminated (1.2 -2 L gas/min in mature ruminant) continuously through the process of eructation.
- The partially digested feed is passed to the omasum, where water is removed (60 - 70 %) and into the abomasum (true stomach) for enzymatic digestion.
- Feed is moved from abomasum to the small intestine where the products of digestion are absorbed.
- The un-digestible portion of the feed is moved to the large intestine and formed into feces.
- The feces is stored in the rectum and expelled through the anus.

Ruminants unlike monogastrics have the ability to recycle excess nitrogen and minerals (Na, K, inorganic P and Cl) through saliva. The nitrogen is

utilized to build microbial proteins. The fates of digestible nutrients (protein, carbohydrate and fat) in ruminants are;

- Conversion to volatile fatty acids
- Transamination through hydrolysis to long chain fatty acids
- Transformation to compounds that are monomers for microbial cell synthesis
- Post rumen digestion

Movement of Digesta along the Digestive Tract

Intestinal contents are propelled through the digestive tract by;

Peristalsis

Peristalsis is an involuntary contraction achieved through the actions of circular muscles and longitudinal muscles along the entire gastrointestinal tract. Activities of the muscles are integrated by the nervous plexus within the tissue layers of the gut. Peristaltic movement helps to;

- transport feed along the digestive tract
- mix digestive juices with the feed
- expose feed nutrients to the intestinal mucous membrane for absorption.

Churning and Mixing

Longitudinal, circular and diagonal muscles of the stomach contract and relax alternately to move stomach contents towards the pyloric sphincter.

Segmentation

Segmentation is a pattern of movement in the small intestine caused by the rhythmic contraction of circular muscles in the intestinal wall. Segmentation squeezes the chyme and mixes it with digestive enzymes and enterocytes.

Haustration

Haustration is a sluggish contraction of the haustra of the colon moves digestion wastes towards the sigmoid colon.

Mass Movement

A strong and sustained movement in the colon occurs that pushes wastes forcibly toward the rectum.

Absorption of Digested Nutrients

The small intestine is the major site of absorption for nutrients after feed digestion; nutrients absorption occurs to a lesser extent in the stomach and large intestine. The specialized lining of the small intestine is folded severally and contains finger-like projections called villi and microvilli (brush border) to increase surface area and absorptive capacity. The villi have specialized absorptive cells called enterocytes

Fat-soluble nutrients are absorbed into lymph while water soluble nutrients are absorbed directly into the bloodstream. Four types of absorption occur in the small intestine;

- Passive diffusion, in which nutrients pass through the enterocytes and into the bloodstream without

the use of a carrier protein or the requirement of energy

- Facilitated diffusion, when nutrients are shuttled across the enterocytes with the help of a carrier protein without the use of energy
- Active transport, involves the use of energy along with a carrier protein to transport nutrients against concentration gradients.
- Endocytosis, occurs when a small amount of the intestinal contents is engulfed by the cell membrane of the enterocyte and released into the interior of the cell.

Blood (through the cardiovascular system), and lymph (the lymphatic system) are the two transport media for nutrients and metabolic wastes in an animal body.

Accessory Organs in Feed Digestion

Organs that are accessory to the gastrointestinal tract and contributing to feed digestion process include the gallbladder, pancreas, and liver. Accessory organs produce, store and secrete chemicals that are involved in digestion.

The Gallbladder

The gallbladder stores bile, a greenish fluid produced by the liver that emulsifies lipids (reduces lipids into small molecules) for easy access to digestive enzymes. The presence of feed protein and lipids in the small intestine causes the release of cholecystokinin (CCK) hormone that will signal the gallbladder to contract and release bile

The Pancreas

Pancreas produces stores and secretes hormones (insulin and glucagon) and pancreatic juice. Pancreatic juice contains enzymes for digestion of carbohydrates (pancreatic amylase), lipids (pancreatic lipase) and proteins (proteases) and bicarbonate, for neutralizing acidic chyme from stomach.

The Liver

The liver is a triangular, wedge-shaped organ inside the rib cage on the right side of the body. Liver, the largest digestive organ and one of the most important organs in the body, performs over 500 different functions one of which is the secretion of bile. Liver also regulates blood glucose level, detoxify blood, manufactures blood protein and stores certain amino acids

Unit 11

Aspects of Metabolism

Metabolism

Metabolism is a collection of chemical reactions that take place in every living cell. Chemical reactions in the body either build up or breakdown substances. Reactions that build-up by combining atoms or molecules to form one larger compound are called anabolism. Reactions that cause larger compounds to breakdown are called catabolism. During catabolism the bonds between molecules are broken and energy is produced; anabolic reactions consume energy. During anabolism new bonds are formed using energy as an input

The Primary Source of Energy in Metabolism

Green plant takes in energy from sunlight (solar energy). The plant uses solar energy and a molecule called chlorophyll to build sugars from water and carbon dioxide during **photosynthesis**. Animal eats to take in solar energy (in the form of sugar), along with other vital cell-building chemicals. Thereafter, the animal body breaks the sugar down so that the energy released can be distributed to, and used as fuel by the body's cells. The process of metabolism converts the fuel in foods into energy needed to power such bodily activities as ;

- moving - contraction of muscles
- thinking - transmission of nerve impulse
- growing - synthesis of proteins
- maintaining body structures - secretion of glands
- reproducing - spermatogenesis

- responding to the environment - growth

Anabolism and Catabolism

Metabolism consists of two major aspects; Anabolism and Catabolism. Anabolism also described as **constructive metabolism** is the total biosynthetic processes whereby large complex molecules are made from small simple molecules. Anabolism is all about building and storing - small molecules are changed into larger, more complex molecules of carbohydrate, protein, and fat. Anabolism supports the growth of new cells, the maintenance of body tissues, and the storage of energy for use in the future. Anabolism transforms waste products of metabolism into less harmful substances; waste products released in the process of catabolism are removed from the body through the skin, kidneys, lungs, and intestines.

Catabolism is also referred to as **destructive metabolism**. It is the breakdown or degradation of complex organic molecules to yield simple molecules and energy. Catabolism is the process that produces the energy required for all activities in the cells. The process helps cells to break down large molecules (mostly carbohydrates and fats) to release energy. The energy released during catabolism provides fuel for anabolism, heats the body, and enables the muscles to contract and the body to move.

Catabolism and Burning are erroneously used interchangeably because the end products of the two processes are similar. Catabolism and burning of glucose or fatty acid molecule are the same - CO_2 and H_2O

Although the body does not burn a substance internally, the maximum energy available in theory for bodily use (catabolism) may be estimated from heat of combustion of the material. Maximum energy from catabolism can neither be more nor less than the heat of combustion of the substance as the reactants and products of catabolism and burning are identical



- 1 mole of fatty acids is almost 4 times as rich in energy as 1 mole of glucose
- Almost half of the energy is lost as heat during catabolism; the remaining half is incorporated into high energy phosphates
- Energy is fixed either by Substrate Level Phosphorylation or Oxidative Phosphorylation

Quiz

Why must chemical reactions in the body (metabolism) occur in small steps?

- ✓ To enable the body derive maximum benefits
- ✓ To protect the cells from damage that may be caused by a single large explosive reaction

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