Ruminant Nutrition / 3 rd Animal Res. /Dr. Suzan

Nutrition definitions and terms

Nutrition: Nutrition involves various chemical reactions and physiological processes, which transform foods into body tissues and activities.

Nutrient: The chemical substances found in the feed materials are necessary for the maintenance, production and health of animals. The chief classes of nutrients include- 25 carbohydrates, 20 amino acids, 15 fatty acids, 15 essential and 10 probably essential minerals, 20 vitamins and water or any chemical compound having specific functions in the nutritive support of animal life.

Nutritionist: A specialist in the problems of nutrition.

Nutrigenomics: Effects of nutrients on gene expression have been studied well in recent years. Nutrigenomics, a branch of nutritional genomics, is the study of the effects of foods and food constituents on gene expression. Nutrigenomics has also been described as the influence of genetic variation on nutrition, where gene expression or single nucleotide polymorphisms (SNPs) are correlated with a nutrient's absorption, metabolism or biological effects.

Introduction

Food is material that, after ingestion by animals, is capable of being digested, absorbed and utilized. In a more general sense we use the term 'food' to describe edible material.

Ruminant comes from the word ″rumen" which is the first major compartment in the four-compartment stomach of the cow, sheep and goat. This structure is the ″furnace" where microbial fermentation takes place. Millions of bacteria, protozoa and fungi live in the rumen and break down energy-rich plant parts, making them digestible for the host animal.

Cattle, sheep and goats have the ability to convert plant carbohydrates and proteins into available nutrients for human use.

Advantages of Ruminants

1-Are not competitive to humans.

2-Convert low nutrient density organic materials into food for humans by anaerobic microbial fermentation of fibrous plants and plant residues in the rumen.

3-Provide services and assist in recycling soil nutrients.

Disadvantages of Ruminants

1•Fermentation of high energy feeds yields to the animal than digestion in the small intestine

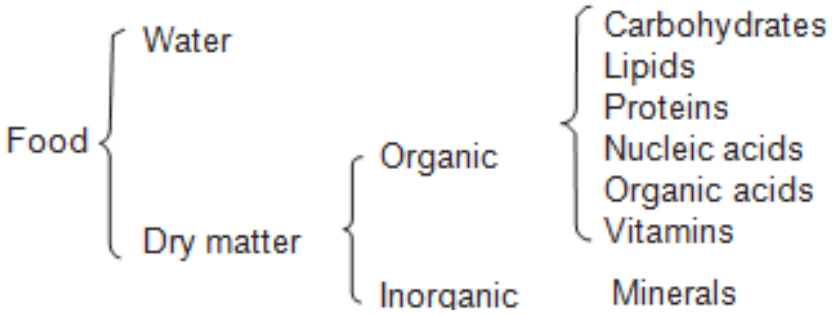
2•Energy losses:

•Heat of fermentation

•Loss of carbon through gas production (CO_2 and CH_4), end products of fermentation

3•Conversion of high quality dietary protein to microbial protein may result in decrease in biological value of the protein.

Chemical composition of plants and animals:



Plants and animals tissues are made up of similar type of chemical substances but their relative amounts are variable. Plants and animals are analyzed by proximate method.

Plants and their by-products show much larger differences in the chemical composition than the animals. Plants synthesize complex materials from simple substances such as carbon dioxide, water, nitrates and other mineral salts from the

soil and energy trapped from the sun by the process of photosynthesis. The greater parts of the energy trapped as a chemical energy within the plant itself and the animals use this energy. Thus, plants store and animals dissipate energy.

Basis of expressing the chemical composition:

The chemical composition of the feed stuffs can be expressed in three ways:-

1. On fresh basis (as such basis) **2. On dry matter basis**

3. On air dry basis

A- Water

Water ranks second only to oxygen in importance, water is the most important dietary essential nutrient. Loss of about 1/5 th of body water is fatal.

Water, which is composed of hydrogen and oxygen in the ratio of 2:1 is not only the largest single constituent of nearly all living plants or animal tissues but it also performs exceedingly important function. It is organic macronutrient. The water content in the plant decreases with the progressive maturity. The growing plants usually have 70 to 80 % of water and seeds have at least 8-10 % of water. Water content in animal body may differ due to age and nutritional status of animal. The animal body may contain 50 to 95 % water. In case of cattle water content is approximately 95 % for the embryo, 75 to 80 % at birth, 68 to 72 % at five month and 50 to 60 % in the mature animals. Whereas blood contains 90-92 %, muscle contains 72-78 % bones contain about 45 %and enamel of teeth which is hardest tissue of body contains 5 % water.

Functions of Water:

1. Water is an essential constituent of the animal body and foodstuff. It makes the food soft and palatable.
2. It helps in regulating body temperature.
3. It helps in absorption and transportation of nutrients to different parts of the body.
4. It is an essential constituent of almost all the juices and secretion of the body.
5. It helps in the excretion of waste product in the form of urine, faeces and respiration from the animal body.

6. It acts as a solvent of many constituents of body nutrients. All the biochemical and physiological reactions take place in liquid medium.

7. It provides shape to the body cells and essential for cell nutrition.

8. During the period of hibernation, metabolic water keeps the animal alive.

9. It helps in maintaining the acid-base balance of the body.

10. It helps in hearing by the ears and visions by the eye.

Sources of water:

1. Drinking water: It is consumed by the animals from the outside source.

2. **Feed**: Moisture content of all the feeds supplies the water requirement of the animal.

3. Metabolic / Oxidation water: It is the water, which is produced due to metabolism of nutrients. It meets 100 % of water requirement in hibernating animals and embryo, 4- 10 % in domestic animals and 16-26 % in desert animals.

A 100 g of each fat, carbohydrate and protein metabolism produce 107, 60 and 40g metabolic water, respectively.

4. Bound water: The water, which is combined with the constituent of protoplasm by either physical or chemical means. It cannot separate easily from protoplasm by freezing at low temperature or by evaporation at high temperature or under dry conditions. Bound water is of special interest in connection with the ability of plants and animals to resist at low temperature and drought condition.

Table (1)Daily average water requirements of domestic animals:

Animal	**liter/day**	**Animal**	**liter/day**
Beef cattle	22-66	Swine	11-19
Dairy cattle	38-110	Chicken	0.2-0.4
Sheep & goats	4-15	Turkeys	0.4-0.6
Horses	30-45		

Factors affecting water requirement:

1. Environment: Increased environmental temperature and humidity enhanced the water requirement in comparison to cold environment because of increased evaporative losses in hot and humid environment.

2. Dietary factor: High fibrous diet like dry roughages increases water requirement than less fibrous diet. Salt and uric acid excretion requires more water. So intake of salt and protein whose end product is uric acid increases the water requirement. If succulent feed is given to animals than dietary water requirement is reduced. Young animals have higher water needs per unit of body size as compare to large animals.

3. Animal factor: Age, stage of growth, level of production, activity, health condition and pregnancy has a direct effect on water requirement.

Other factors are salinity and sulfate content of water, temperature of water. Birds require less water as compared to mammals because uric acid is the end product of protein metabolism in birds as urea in mammals.

Water metabolism:

It includes absorption, homeostasis and excretion.

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1. **Absorption**: Absorption takes place from all the parts of G.I.T. (gastro intestinal tract) mainly large intestine. A number of factors like osmotic relations inside the small intestine and nature of the carbohydrate component of the feed determine the extent to which absorption actually occurs. Water is most readily absorbed when it is taken alone as beverage, or when taken with food that after digestion forms a solution with osmotic pressure lowers than that of blood plasma.

2. Homeostasis: It is the maintenance of uniformity and stability of water. Water balance is affected by total intake of water and losses arising from urine, faeces, milk, saliva, sweating and vaporization from respiratory tissues.

3. Excretion: Water if excreted from body by evaporation through skin, perspiration, through faeces, urine, milk, tear and saliva. Amount lost via various routes are

affected by amount of milk produced, ambient temperature, humidity, physical activity of the animal, respiration rate, water consumption and dietary factor.

Symptoms of deprivation of water:

Anorexia, discomfort and inco-ordination in movement, decreased blood pressure and cardiac output increased respiration rate, shrivelled skin, increased body temperature, delirium and death if deficiency of water continue.

Toxic elements in water: Universal solvent property of water sometime creates problems. Water can dissolve unwanted material. Such water should not be used for drinking purpose. Amount of total dissolved solids (TDS) is a measure of the usefulness of water for animals. A level of less than 3,000 mg/ liter TDS can be tolerated by the animals but higher amount is harmful to animals.

B- Dry matter and its components

The dry matter (DM) of foods is conveniently divided into **organic** and **inorganic** material, although in living organisms there is no such sharp distinction. Many organic compounds contain mineral elements as structural components. Proteins, for example, contain sulphur, and many lipids and carbohydrates contain phosphorus.

In contrast, **the carbohydrate content of the animal body is very low**. One of the main reasons for the **difference between plants and animals is that, whereas the cell walls of plants consist of carbohydrate material, mainly cellulose, the walls of animal cells are composed almost entirely of lipid and protein.** Furthermore, **plants store energy** largely in the form of carbohydrates such as **starch and fructans**, whereas an animal's main energy store is in the form of **lipid**.

The **lipid content** of the animal body is variable and is related to **age**, the older animal containing a much greater proportion than the young animal. The

lipid content of living plants is relatively low, that of pasture grass, for example, being 4-5% DM.

In both plants and animals, proteins are the major nitrogen-containing compounds. In plants, in which most of the protein is present as enzymes, the concentration is high in the young growing plant and falls as the plant matures. In animals, muscle, skin, hair, feathers, wool and nails consist mainly of protein.

Like proteins, nucleic acids are also nitrogen-containing compounds and they play a basic role in the synthesis of proteins in all living organisms. They also carry the genetic information of the living cell.

The **organic acids** that occur in plants and animals include:

Citric, malic, fumaric, succinic and pyruvic acids.

Although these are normally present in small quantities, they nevertheless play an important role as intermediates in the general metabolism of the cell. Other organic acids occur as **fermentation products** in the rumen, or in silage, and these **include:**

Acetic, propionic, butyric and lactic acids.

Vitamins are present in plants and animals in minute amounts, and many of them are important as components of enzyme systems. An **important difference between plants and animals is that, whereas the former can synthesise all the vitamins they require for metabolism, animals cannot, or have very limited powers of synthesis, and are dependent upon an external supply.**

The **inorganic matter** contains all those elements present in plants and animals other than **carbon, hydrogen, oxygen and nitrogen. Calcium and phosphorus** are the major inorganic components of animals, whereas **potassium and silicon** are the main inorganic elements in plants.

The principles of ruminant nutrition

1- Ruminants are adapted to use forage because of microbes in their rumen.

2- To maintain ruminant health and productivity, feed the rumen microbes, which in turn will feed the ruminant.

3- Ruminant nutritional needs change depending on age, stage of production, and weather.

4- Adequate quantities of green forage can supply most if not all the energy and protein that ruminant needs.

5- Forage nutritional composition changes depending on plant maturity, species, season, moisture, and grazing system.

6- Supplementation may be necessary when grass is short, too mature, dormant, or if animal needs require it (i.e., high-producing dairy animal).

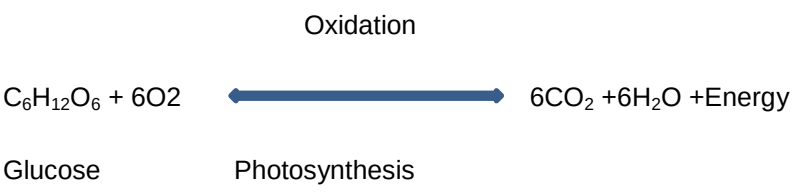
7-Excessive supplementation may reduce the ability of the rumen microbes to use forage.

1- Carbohydrates

Definition of carbohydrates: Carbohydrates may be defined as polyhydroxy aldehyde, ketones or acids and their derivatives or compounds that yield these derivatives on hydrolysis. The carbohydrates are neutral chemical compounds containing the element carbon, hydrogen and oxygen,

Carbohydrates are called carbohydrates because they are essentially hydrates of carbon (i.e. they are composed of carbon and water and have a composition of $(CH_2O)_{n.}$

They are primarily produced by plants and form a very large group of naturally occurring organic substances. Some common examples are cane sugar, glucose, starch, etc. Carbohydrates are formed in the plants by photosynthesis from carbon dioxide and water in the presence of sunlight



One of the examples of carbohydrate where such ratio is not found in the sugar deoxyribose ($C_5H_{10}O_4$) which is a constituent of DNA. Whereas acetic acid ($C_2H_4O_2$) and lactic acid ($C_3H_6O_3$) can be represented as hydrates of carbon but are not carbohydrates. The carbohydrates serve as both structural and reserve material in the plant. The animal body contains less than **1 %** carbohydrate, which are present in blood, muscles and liver. The carbohydrate present in animal body is also known as animal starch or **glycogen**.

Based upon their digestibility and solubility the carbohydrates can be divided into two groups:-

(a) Soluble carbohydrates: They are called nitrogen free extract (NFE) and include simple sugar, starch and hemicellulose, which are easily digestible in the body.

(b) Insoluble carbohydrates: They include hard fibrous substance like crude fiber, cellulose and lignin. They are less digestible by non-ruminants and easily digested in ruminants by rumen microflora and microfauna.

Functions of Carbohydrates in animal nutrition:

1. Carbohydrates serve as a major source of energy in animal body.
2. They are essential components of production, temperature control.
3. They are essential components of milk as lactose.
4. They are stored as glycogen, excess of carbohydrates in the diet is converted into fat and stored in the fat depot. These are reserve energy materials of the body in liver and muscles of animals and starch in plants.
5. Carbohydrates are helpful in absorption of calcium and phosphorus in younger animals.
6. They help the secretion of digestive juices in gastrointestinal tract.
7. They provide suitable environment for the growth of rumen bacteria and protozoa.
8. They help movement of food.
9. They maintain the glucose level of plasma.

10. They are also component of several important bio-chemical compounds such as nucleic acids, coenzymes and blood group substance.

11. They play a key role in the metabolism of amino acids and fatty acids.

Carbohydrate digestion in the rumen:

The major carbohydrates of the ruminant's diet consist of cellulose, hemicellulose and other carbohydrates which cannot be hydrolyzed by the enzymes secreted by the animals in the digestive tract but broken down by enzymes secreted by rumen microorganisms with the production of volatile fatty acids and gases. The bacteria, which help in carbohydrate digestion, are as follows:-

	Substrate	***Species***
1.	**Cellulose digester**	*1. Bacteriodes succinogenes* *2. Butyrivibrio fibrisolvens* *3. Clostridium lochheadii* *4. Clostridium longisporum* *5. Cillobacterium cellulosolvens* *6. Acetigenic rod* *7. Ruminococci sp.*
2.	**Starch digester**	*1. Clostridium lochheadii* *2. Bacteriodes succinogenes* *3. Butyrivibrio fibrisolvens* *4. Streptococcus bovis* *5. Bacteriodes amylophilus* *6. Bacteriodes ruminocola* *7. Succinimonas amylolytica* *8. Selenomonas ruminantium*
3.	**Hemicellulose digester**	*1. Eubacterium sp.* *2. Bacteriodes ruminicola* *3. Bacteriodes amylogenes* *4. Ruminococcus flavefaciens* *5. Ruminococcus albus*
4.	**Sugar fermenting bacteria**	*1. Lactobacilli sp.*
5.	**Methanogenic bacteria**	*Methanobacterium ruminantium*
6.	**Proteolytic bacteria**	*All bacteria related to carbohydrate fermentation.*
7.	**Lipolytic bacteria**	*Anaerovibrio Lipolytica*

The soluble carbohydrates are rapidly fermented, starches are less rapidly fermented, whereas, the structural carbohydrates like cellulose and hemicellulose

are slowly fermented. All carbohydrates are converted into pyruvic acid as shown below.

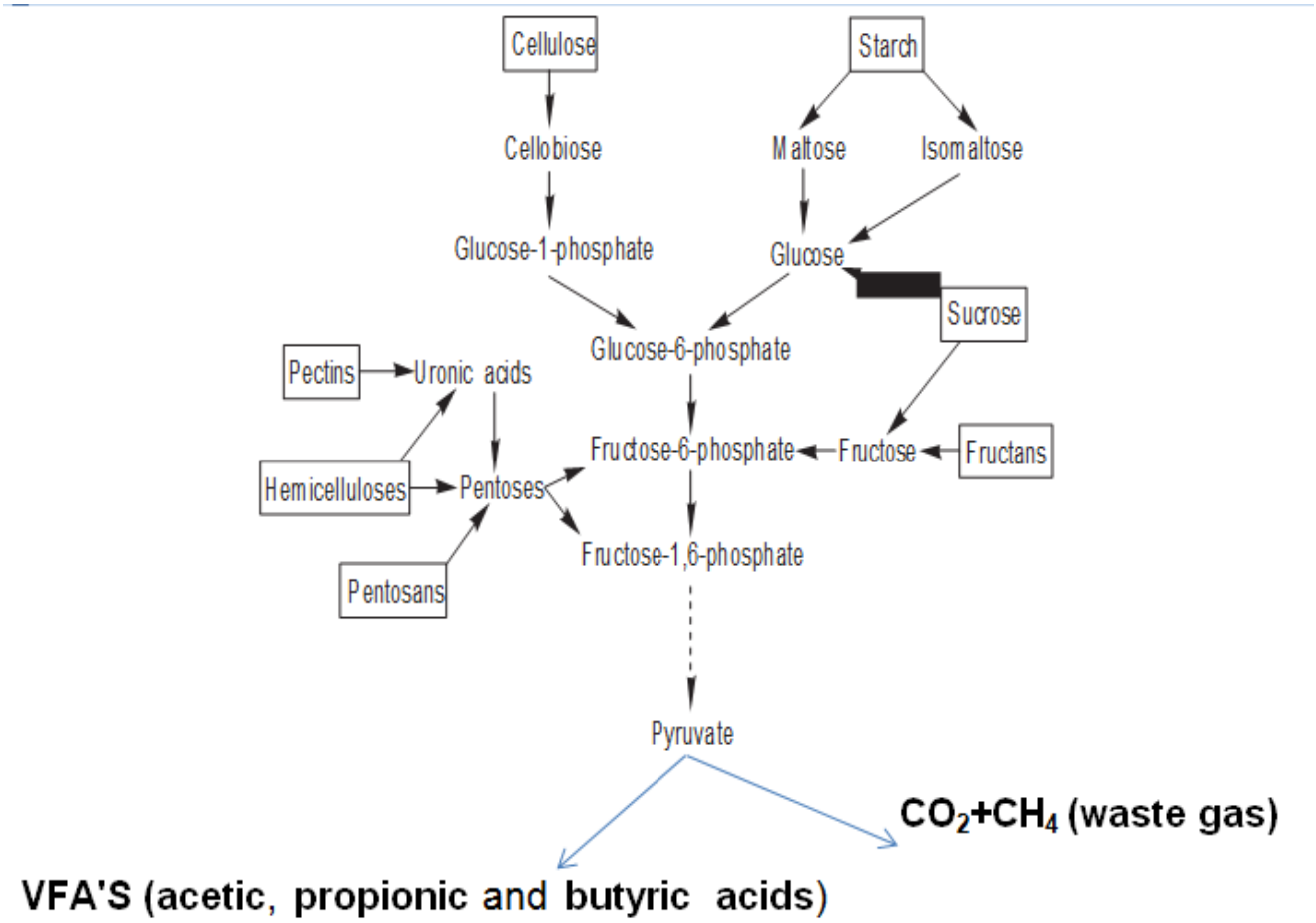
The diet of the ruminant contains considerable quantities of cellulose, hemicelluloses, starch and water-soluble carbohydrates that are mainly in the form of fructans. Thus, in young pasture herbage, which is frequently the sole food of the ruminant.

The breakdown of carbohydrates in the rumen may be divided into two stages:

The first of which is the digestion of complex carbohydrates to simple sugars. This is brought about by extracellular microbial enzymes.

second stage/ The simple sugars produced in the first stage of carbohydrate digestion in the rumen are rarely detectable in the rumen liquor because they are immediately taken up and metabolised intracellularly by the microorganisms.

Fig (1) Digestion and metabolism of carbohydrates in the rumen



The bacteria and protozoa mainly responsible for fermentation in the digestive tract are mainly strict anaerobe although, there may be a small number of facultative anaerobes. The normal concentration of bacteria in rumen liquor is 10^{11} bacteria /ml. and protozoa are 10^{6} / ml of rumen content.

Volatile fatty acid production in rumen:

The feeds, which is ingested by the animals broken down to volatile fatty acids like acetic, propionic and butyric acids via pyruvic acid. Higher fatty acids like valeric and isovaleric acid etc. are also formed in smaller amounts. With normal diets the predominant acid is acetic acid followed by propionic acid and butyric acid. Volatile fatty acids represent in the following proportions.

1. Acetic acid 60-70 %

2. Propionic acid 15-20 %

3. Butyric acid 10-15 %

4. Valeric and isovaleric acid present in traces.

On an exclusive **roughage** diet the production of **acetic acid** is highest.

As the **concentrates** in the diet are increased, the production of acetic acid reduces and that of **propionic acid** increases.

Lactic acid is also formed as an intermediate product but is fermented to acetic and propionic acid.

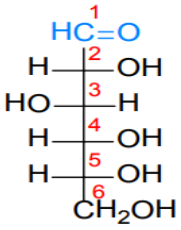
Classification

Carbohydrates are classified into three main classes:

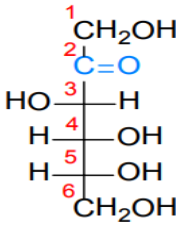
A/Monosaccharides: The simplest form of carbohydrates is the monosaccharide. 'Mono' means 'one' and 'saccharide' means 'sugar'. Monosaccharaides are polyhydroxy aldehyde or ketone that cannot be hydrolyzed further to give simpler

sugar such as Glucose(blood sugar), Fructose (fruit sugar) (6C sugars) and Ribose (5C sugars) (found in RNA and DNA it is synthesized from glucose in the body).

o Not needed in the diet because it is



Glucose
(Aldose)



Fructose
(Ketose)

B. Disaccharides: They give two monosaccharide units on hydrolysis, which may be the same or different. For example,

1. Lactose (milk sugar) which hydrolyses into two molecules of glucose and galactos.

Lactase

Lactose → Glucose + Galactose

2. Sucrose (found in most plants, cane and beet sugar) which hydrolyses into two molecules of glucose and fructose:

Sucrase

Sucrose → Glucose + Fructose

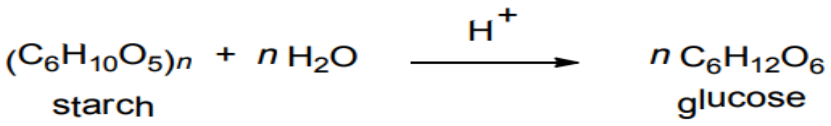
3. Maltose it is obtained from the hydrolysis of starch. Which hydrolyses into two molecules of glucose.

Maltase

Maltose → Glucose + Glucose

C/ Polysaccharides: These carbohydrates give a large number of monosaccharide units on hydrolysis, these monosaccharide units are joined together by oxide bridges.

Polysaccharides usually regarded as important in animal nutrition are:



1-Starch: Many plants store energy in the form of starch. Starch is major component of most livestock rations (especially fattening rations) and is highly digestible. Hence, it is a primary energy source for livestock.

2-Inolin: is similar to starch except it hydrolyzes to fructose rather than glucose.

3- Glycogen: is sometimes referred to as animal starch. And its storage form of glucose in animals and humans, Synthesized and stored in liver and muscle (respectively).

4-Hemicellulose: is a term used to denote a group of substance that lie chemically between sugars and starch on the one hand and cellulose on the other. Hemicellulose are distributed widely in forage crops and certain other materials frequently used for feeding purposes.

5-Cellulose: is a principal constituent of the cell wall of plants. It is most abundant in the more fibrous feed. Generally, it is low digestibility. Cattle, sheep, goat and horses digest cellulose fairly effectively; it is only digested slightly by swine. Cellulose can be hydrolyzed by special processes to glucose.

6-Lignin: is NOT a carbohydrate, not able to be digested but it is bound to cellulose.

2- Proteins

Proteins and other nitrogenous compounds

Proteins are complex organic compounds. In common with carbohydrates and fats they contain carbon, hydrogen and oxygen, but in addition they all

contain **nitrogen** and generally **sulphur**.

Protein: Composed of Amino Acids (AA) all amino acids are needed by the animal and there are two types of AA:

1-Essential Amino Acids

Essential AAs cannot be synthesized at the appropriate level and must be supplied in the diet.

2-Non-essential Amino Acids

Used by the animal, but they are also synthesized by the animal.

Table 2- Amino Acids

Essential AA	Nonessential AA
Arginine	Alanine
Histidine	Aspartic acid
Isoleucine	Citrulline
Leucine	Cystine
Lysine	Glutamic acid
Methionine	Glycine*
Phenylalanine	Hydroxyproline
Threonine	Proline*
Tryptophan	Serine
Valine	Tyrosine
Taurine	*Additional amino acids required by chicks

Sources of Rumen Nitrogen

1- Feed

-Protein nitrogen

-Protein supplements (SBM, CSM, grains, forages, silages...

2- Nonprotein nitrogen (NPN)

-Usually means urea

-However, from 5% of N in grains to 50% of N in silage and immature forages can be NPN

3- Endogenous (recycled) Nitrogein

-Saliva

-Rumen wall

In the case of the ruminant, all the essential amino acids can be synthesised by the rumen microorganisms, which theoretically makes this class of animal **independent** of a dietary source once the rumen microorganisms have become established.

However, the supply of amino acids from microbial protein is **limiting in quantity and quality** for maximum rates of growth in young animals and for maximum milk production.

The biological value of microbial protein is limited by its content of certain essential amino acids, **particularly lysine and methionine**. For maximum productivity the microbial protein must be supplemented with a supply of dietary amino acids, from foods or synthetic amino acids.

Peptides

Peptides are built up from amino acids by means of a linkage between the α-carboxyl of one amino acid and the α-amino group of another acid, this type of linkage is known as the **peptide linkage**; a dipeptide has been produced from two amino acids. Large numbers of amino acids can be joined together to produce polypeptides.

Classification of proteins:

Proteins may be classified into three main groups according to their shape, solubility and chemical composition.

A- Fibrous Proteins: These proteins are insoluble and very resistant to animal digestive enzymes. They are composed of elongated, filamentous chains, which are joined together by cross linkages. **They are as follows:**

1. Collagens are the main proteins of connective tissues

2. Elastin is the protein found in elastic tissues such as tendon and arteries. It is rich in alanine and glycine

3. Keratins are the protein of hair, hoof, nails etc.

These proteins are very rich in Sulphur containing amino acid cysteine. Wool protein contains about 4 % Sulphur.

B- Globular Proteins: This group includes all the enzymes, antigens and hormones that are protein.

1. Albumin is water-soluble and heat coagulable and occurs in eggs, milk, blood and many plants.

2. Globulins are present in eggs, milk and blood and are the main reserve protein source in seed.

3. Histones are basic protein, which occur in cell nucleus where they are associated with DNA. Large quantities of histidine and lysine.

4. Protamines are associated with nucleic acid and are found in large quantities in the nature germ cells of vertebrates. Protamines are rich in arginine.

C- Conjugated Proteins: Conjugated proteins are composed of simple protein combined with some non-protein substances as prosthetic group.

1. Phosphoprotein Casein of milk and phosvitin of egg yolk are the best known phosphoproteins.

2. Glycoproteins are conjugated proteins with one or more heterosaccharides as prosthetic groups. Glycoproteins are components of mucous.

3**. Lipoproteins** they are the main components of cell membranes

4. Chromoproteins contain pigment as a prosthetic group. Examples are haemoglobin, and flavoproteins.

5. Nucleoproteins conjugated with nucleic acid.

6. Metalloproteins a large group of enzyme proteins contain metallic elements, such as Fe, Co, Mn, Zn,' Cu, Mg, etc. which are essential part of these proteins.

Function of proteins:

1. Proteins form muscles and tissues of the body; hence it is essential for the growth and development of the body.
2. They help in maintaining the loss of body tissues and muscles.
3. They help in the formation of enzymes, hormones, antigen, antibody, digestive juices of the body and regulate body osmotic pressure and acid-base balance.
4. They help in the repair of body cells as well as for the production of new cells.
5. They also supply energy to the body.
6. They are essential for the formation of egg, milk protein, wool and hairs of the animals.
7. They provide the basic cellular matrix within which the bone mineral matter is deposited.
8. Under condition of non-digestion and no-chances for denaturation, the protein accumulates inside the cells and produce toxicity. i.e. venoms of snakes and insects are infected by biting into the blood.
9. Endorphins (peptide) are found in brain and are involved in the suppression of pain.

Mechanism of protein degradation:

1- Protein → (Microbial Proteases) → peptides
2- Peptides → (peptidases) → amino acid
3- amino acid → (deaminases) → carbon skeleton+ ammonia
4- carbon skeleton → (fermentation) → VFA's

Digestion of protein

The digestion of protein in the rumen is illustrated in scheme(3). Food proteins are hydrolysed to peptides and amino acids by rumen microorganisms, but some amino acids are degraded further, to organic acids, ammonia and carbon dioxide.

The ammonia produced, together with some small peptides and free amino acids, is utilised by the rumen organisms to synthesise microbial proteins.

Some of the microbial protein is broken down in the rumen and its nitrogen is recycled (i.e. taken up by microorganisms).

When the organisms are carried through to the abomasum and small intestine, their cell proteins are digested and absorbed.

The extent to which dietary protein is degraded to ammonia in the rumen, and conversely the extent to which it escapes rumen degradation and is subsequently digested in the small intestine.

The **greater part** (and sometimes all) of the protein reaching the ruminant's small intestine will be **microbial protein** and the **lesser part** will be **undegraded** food protein.

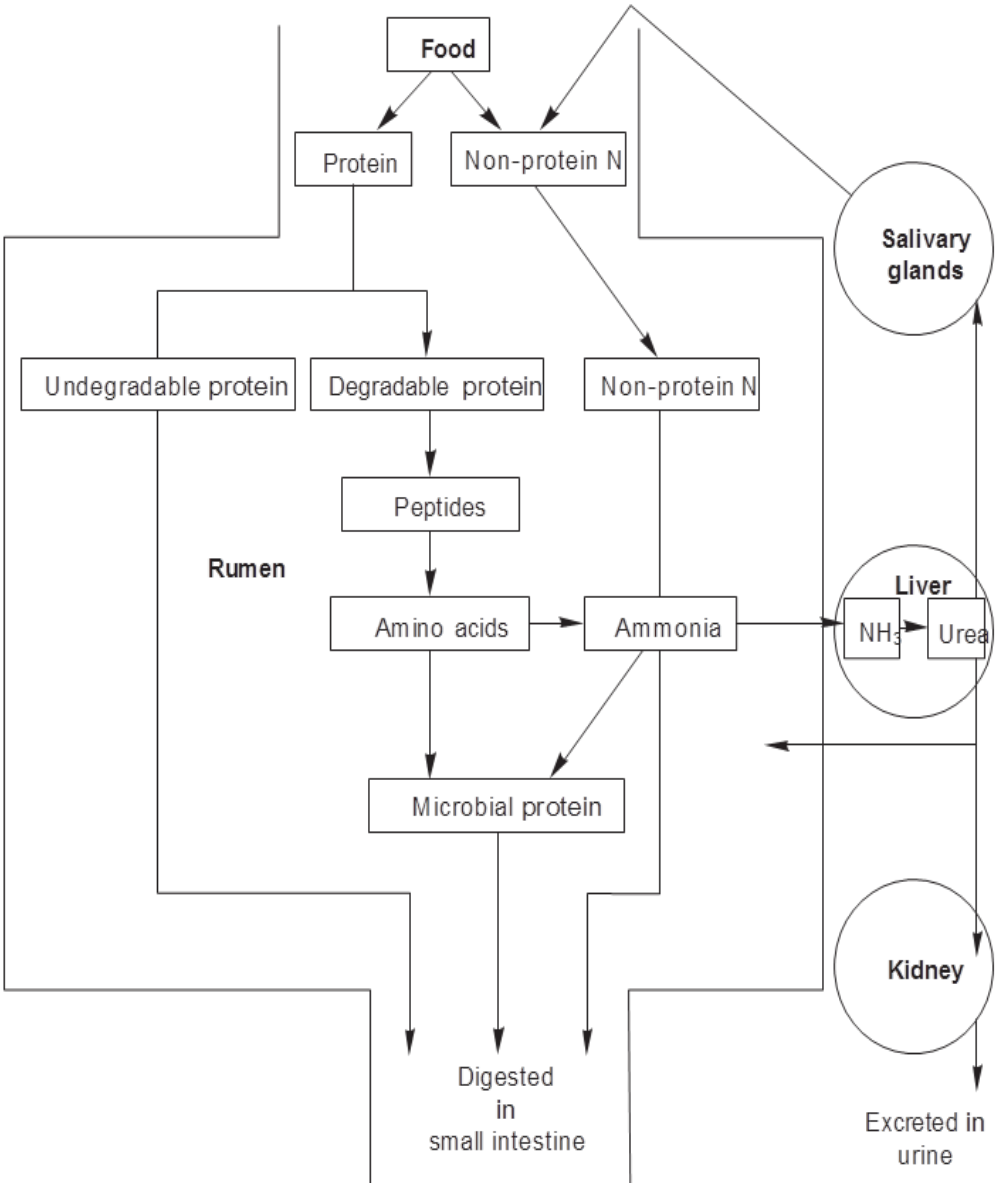
The ammonia in rumen liquor is the key intermediate in microbial degradation and synthesis of protein. When ammonia will accumulate in rumen liquor and the optimum concentration will be exceeded, ammonia is absorbed into the blood, carried to the liver and converted to urea .Some of this urea may be returned to the rumen via the saliva and also directly through the rumen wall 'recycled' but the greater part is excreted in the urine and thus wasted.

Urea = 46 % N

Urea = 287.5% CP equivalent

46% x 6.25 = 287.5% CP equivalent

Fig (2) Digestion and metabolism of nitrogenous compounds in the rumen.



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