

1. Introduction to Animal Nutrition

It is obvious that animals provide numerous products and services. They serve as source of quality food, power, savings and investments, different social and cultural functions, to earn foreign currency, Manure, etc.

Animals however are **dependent** on plants for the continuation of their function because plants by asset of possessing chemical compounds called **chlorophyll** are in a position to convert the less complex inorganic forms of nutrients like nitrates, mineral salts, H_2O , CO_2 into organic or highly complex type of chemical compounds. Inorganic compounds are obtained from the soil or air for photosynthesis and absorbed by plants and by the help of chlorophyll and radiant energy (energy from the sun), the inorganic substances will be converted to organic (more complex) compounds. On the contrary animals are not able to transfer less complex inorganic substances to more complex organic matter due to the lack of chlorophyll. By asset of this difference animals are dependent on plants for the perpetuation of their body tissues.

Animals in general require both inorganic and organic form of nutrients to renew old tissue and build new tissue. The animal system needs inorganic nutrients mainly in the form of minerals. Animals need organic nutrients in the form of carbohydrates (largest quantity takes by the animals, as most plant parts are made of carbohydrates), protein, Lipid (fat specifically) and vitamins in the order of quantity consumed with the exception of proteins and lipids as some feeds contain large amounts of lipids.

The primary source of organic material is totally plant tissues. Inorganic source of nutrients mainly come from consumption of plant material, but it is possible to give animals with actually not plant but in the form of pure nutrients (pure mineral) but the majority come originally from plant tissue.

The subject matter of animal nutrition is the study of the phenomena where by one studies.

- ❖ The chemical structure (configuration) of the different nutrients.
- ❖ To understand how animal system actually functions, how the animals take the plant material and how the various chemical reactions and physiological processes, which transform food into body tissues and activities takes place. This involves the ingestion, digestion and absorption of various nutrients, their transport to all body cells, and the removal of unusable elements & waste products of metabolism.
- ❖ It is also concerned with the nature of the feed and feed nutrients, nature and requirement of animals of different regions and different purposes (produce, reproduce, work), also contain study of transformation of feed elements to animal products.

Nutritionally farm animals are divided into ruminants and non-ruminants, based on the anatomical structure of the digestive system of farm animals.

Ruminants are animals having partitioned large stomach where as non-ruminants (monogastrics) have simple stomach, not as complicated as ruminant stomach. Ruminants having large size and partitioned stomach create favourable environment for microbial symbiotic activity such as favourable pH, temperature and anaerobic condition. To this effect millions of micro-organisms thrive in the reticulo-rumen of ruminants, and these micro-organisms have the ability to produce enzymes which can hydrolyse the fibrous (cellulose) part of the feed enabling the animals to utilise such feeds.

The monogastric stomach on the other hand is simple and its internal environment not allows the development of micro-organisms. So these animals are not in a position to utilise highly fibrous feeds. Therefore, the nutrients in the two groups differ. In the case of ruminants one can give

them with fibrous feeds or cellulose rich diets and by virtue of the presence of micro-organisms in their stomach, the inedible products will be converted to edible (available) product in which case the ruminant can utilise and transfer it to highly valuable and quality products such as meat and milk (hides, skin, hair, etc).

In the case of monogastrics, which lack the symbiotic effect of micro-organisms as a result of their simple stomach, they require very low fibrous feeds as grains and there is a competition for such feeds with humans (example, poultry, and swine). But grains are given to ruminants in intensive animals production systems like for fattening.

1.1. Significance of animal nutrition in livestock production

Animal Nutrition can be described as the study of food/feed in the way they are utilized in the animal body for the purpose of body maintenance, production and reproduction in the most efficient and economic manner. The works of animal nutrition as a result are described towards establishing relationships between nutrient intake and the response by animals. The response by the animals refers to what are called performance. Performance is mostly represented by the condition of health, growth and perpetuation of life/reproduction/. The study of animal nutrition is interlinked with biological investigations mainly with those related physiology and biochemistry.

Poor nutrition results in low rates of production and reproduction as well as increases in susceptibility of livestock diseases and subsequently mortality. Biologically, about two-third of the improvement in livestock productivity is often attributed to nutrition since animal production is basically a conversion of feed into animal products. In economic terms, feed cost accounts for about 70% of the total cost of livestock production indicating the feasibility of livestock enterprises is a function of the type of feed and feeding system. Some estimates of the impact of optimal utilization of feed resources on

improvement of the productivity of the sub-sector in the tropics suggest scenarios as high as five-fold improvement in output. It is estimated that there is a 40% deficit in the national feed balance. This is again aggravated by seasonal availability of forage and crop residues in the highlands and by erratic rainfall in the lowlands. The problem is further exacerbating by the associated poor husbandry practices that lower productivity further.

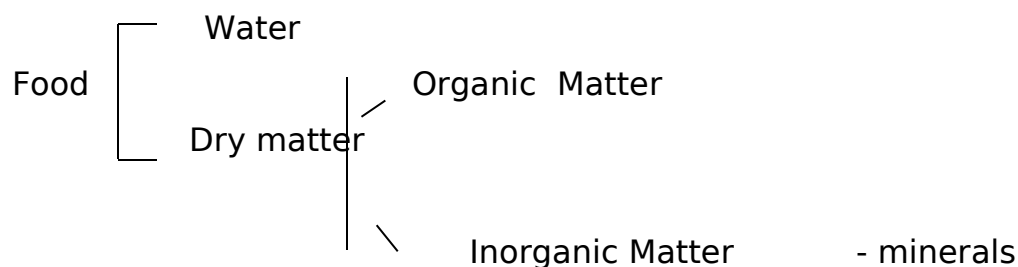
Ensuring high performance through adequate control of nutrition is determined by three important and interrelated considerations:

- The availability of nutrients;
- Type of feeding system and;
- The level of feeding management

1.2 The Animal and Its Feed

Feed consists of water and Dry Matter (DM). If the water content in food is 75%, the DM content is 25%. Although water is very important, the DM is crucial to the composition of a ration. More food is needed when it contains more water.

The main components of a feeds are:



1.2.1. Water

Water is vital to any animal. The bodies of young animals may consist up to 80% of their live weight. Older, and especially fat animals, have less water in their bodies (down to 50%).

Feeds can contain both high and low water percentages. Examples of feeds with high water contents are young grass ($\pm 15\%$ DM) and cabbage ($< 10\%$ DM). Hay and concentrates are feeds with low water contents (85-90% DM).

An animal obtains water from three sources: drinking water, water present in food and metabolic water. The latter is formed during metabolism by oxidation of hydrogen (H) containing organic nutrients. Water leaves the body with urine, faeces, milk, and as vapour via the lungs (respiration) and the skin (perspiration). There is no evidence that, under normal conditions, an excess of drinking water is harmful. If water is offered ad lib, animals normally drink what they require.

It is important to note that a lack of water in the diet results in a reduced appetite: a cow will

eat less! This might affect DM intake which can have many consequences.

Dairy cattle require water for:

1. Chewing and swallowing (saliva)
2. Transport of nutrients around the body
3. Formation and maintenance of body tissues
4. Disposal of waste products
5. Regulation of the body temperature
6. Milk production

1.2.2. Dry Matter (DM)

All valuable feed substances are contained in the DM. If the DM% in a feed is known, it is

possible to calculate how many kg DM an animal obtains from the feedstuff (and how many

kg concentrate is needed as a supplement according to the norms for the production level).

The DM of a feedstuff can be divided into two groups:

- Organic Matter (OM)
- Inorganic Matter (IOM)

1.3. Nutrition Technical Terminology

Ad libitum: Feeding system where animals are given unlimited access to feed. Synonymous terms include full feeding, free choice, self-feeding.

Air- dry basis: Expression of the composition of feedstuffs. This may be actual i.e. referring to feed that is dried by means of natural air movement in the open or assumed dry matter content. Assumed to be 90% dry matter.

Animal Protein: Protein of animal origin derived from slaughterhouses, animal product processing plants that can be used as ingredients in feed mixtures.

Anti-nutrients. Some feed ingredients and potential feeds contain factors that inhibit the digestive process causing reduced growth, diarrhea or pasting. They limit the amount of some feed ingredients that can be added to the final feed. The anti-nutritional factors in some feed materials such as beans can be destroyed by heat treatment (cooking).

Anti-oxidant: A chemical compound that prevents oxidative rancidity of polyunsaturated fats; added to feed ingredients or feed mixtures for protection against oxidation.

Appetite: Desire to eat; could also be used to refer to the weight of feed dry matter consumed as a percentage of live weight.

As fed: refers to feed as normally fed to animals. The term "as collected" is used for materials which are normally not fed to animals i.e. faeces, urine.

Available Nutrient: A nutrient that can be digested, absorbed and used in the body for some useful purpose.

Average Daily Gain (ADG): The mean daily increase in the live weight of an animal.

Balanced Daily Ration: A combination of feeds fed at a time or in portions at intervals, as will provide the essential nutrients in such amounts as will properly nourish an animal for a 24-hour period.

Balanced Ration: A combination of feeds that provides the essential nutrients in the proper amounts and proportions to adequately nourish a particular animal.

Biological Value: the usable proportion of the protein of a feed or feed mixture by an animal. It is a measure of protein quality. A protein that has a high biological value is said to be of good quality.

Blend: A mixture, such that, the constituent parts are rendered indistinguishable from one another.

By-product feeds: Secondary products from plant and animal processing and industrial manufacturing that may be used for animal feeding.

Cake (press cake): Material resulting as a by-product from the processing of oil seeds to remove oil using the mechanical or expeller method.

Calorie: amount of heat energy required to raise the temperature of one gram of water from 14.5 to 15.5 °C used as a measure of feed energy.

Chaff: Glumes, husks, or other feed covering together with other plant parts, separated from seed in threshing or processing.

Commercial Feeds: Feeds mixed by commercial feed manufacturers that specialize in the business as opposed to home mixing.

Compaction: A condition when feed in the stomach and intestines of an animal becomes closely packed causing constipation and/ or digestive disturbances.

Complete Ration: All feedstuff (forages, grains, processed feeds etc.) combined in one feed mixture that is nutritionally adequate for a specific animal in a specific physiological state.

Concentrate: A class of feedstuff low in fiber (< 18% Crude Fiber)

Creep: An enclosure or feeder used for supplemental feeding of nursing young that excludes their dams.

Crop- residue: Portion of plant growth that remains after harvesting grain or seed crop e.g. Straws, stalks, husks, cobs etc.

Deficiency: Lack or shortage of one or more basic nutrients.

Diet: Feed ingredient or mixture of ingredients including water regularly offered to or consumed by an animal.

Digestibility: The proportion of feed that is not excreted in the faeces and, thus, assumed to be absorbed.

Digestion: Process of changing food to a form that can be absorbed from the digestive tract by the body tissues (mainly the intestines).

Diluent: an edible substance used to mix with and reduce the concentration of nutrients and/or additives to make them more acceptable to animals, safer to use and more capable of being mixed uniformly in a feed mixture.

Dry matter basis: an expression of the level of a nutrient contained in a feed on the basis that the material contains no moisture. Synonymous with 100% Dry matter basis, moisture free, Oven dry.

Energy feeds: feeds high in energy and low in fiber (< 18% Crude Fiber) e.g. Grains.

Expeller process: A process for the mechanical extraction of oil from oil seeds involving the use of a screw press.

Feed (feedstuff): Any naturally occurring material suitable for feeding animals.

Feed Additives: Non-nutritive products that improve animal performance or preserve feeds.

Feed conversion Efficiency: Measure of the efficiency of feed utilization. It is expressed as units of feed per unit of animal product - meat, milk or eggs.

Feeder's Margin: Difference between the cost per unit weight of feeder animals and the selling price per unit weight of the same animals when finished.

Feeding Standards: Estimates of nutrient requirements for a specific function in a given environment.

Feedlot: A lot or plot of land on which animals are fed or finished for marketing.

Fibrous Feed: Feed high in cellulose and/ or lignin.

Finish: To fatten a slaughter animal. The term may also refer to the degree of fatness of such an animal.

Flushing: The practice of feeding breeding animals more generously sometime before mating to improve fertility.

Fodder: Coarse feeds such as corn or Sorghum Stover.

Forage: Vegetative parts of plants fed to livestock in the fresh, dried or ensiled form.

Formula Feed: Feed mixture consisting of ingredients mixed and processed in specific proportions.

Free choice: A feeding system by which animals are given unlimited access to the separate components or groups of components constituting the diet.

Full Feed: A situation where animals are being offered as much feed as they will consume safely without going off-feed.

Gestation ration. Ration given to pregnant animals during the last trimester to provide for the additional nutrients needed for proper growth of the fetus and to keep the mother fit for optimum milk production on calving.

Grits: Coarsely ground grain, from which the bran and germ have been removed, usually screened to uniform particle size.

Hulls: outer covering of dry grain or other seed, especially when dry.

Ingredient: Constituent feed of a feed mixture.

2. Classification and Characteristics of Feedstuff

2.1 Forages and roughages

In certain books they are used interchangeably but in most books forage is used to refer fresh plant materials strictly speaking to grazing and browsing or forages are plants grown to be used specifically for feeding animals such as grasses and legumes whereas roughage is meant to imply either dry or fresh plant material used for animal feeding. By definition roughage is any material suitable for feeding of livestock which contains more than 18% crude fiber. Therefore, roughages are bulky feeds high in fiber and low in energy. Types of roughage include pasture and other grazed forages, hay and dehydrated forages, silage and crop residues and other by-products of agriculture.

2.2 Concentrates

Concentrates are livestock feeds provide the basic nutrients required for animal production, including energy, proteins, minerals, vitamins and other micro-nutrients. Concentrates are feeds that contain a high density of nutrients, usually low in crude fiber content (less than 18% of dry matter (DM)) and high in total digestible nutrients more than 60%. Concentrates may be high in energy, referred to as **energy concentrates**, such as cereals and milling by-products, or high in protein, with over 20% crude protein, referred to as **protein concentrates**. Concentrates can be fed in raw or milled forms.

Raw materials for concentrate feeds

Raw materials for concentrate feeds are commonly classified into the following categories:

Cereals: the main cereals are rice, wheat, barley, oats, rye, maize, sorghum and millet

Grains: all cereals except rice

Coarse grains: all cereals except wheat and rice

Food grains: grains used for human food consumption

Feed grains: unmilled grains to be used as livestock feeds

Milling by-products: by-products from the milling of cereals and pulses

Feed-grain substitutes: dried **roots and tubers** (chiefly cassava and sweet potatoes), or by-products of crop processing such as molasses, maize gluten feed and brewery grains, dried citrus pulp etc. In some classifications, 'roots and tubers' are classed separately while the latter kinds of feeds may be regarded as 'other concentrates' or 'non-conventional concentrates'.

Oil meals and cakes: products of oilseeds (including copra, cotton seed, groundnuts, linseed, palm kernels, rapeseed, sunflower seed and soyabeans) and fish after extraction

2.3 By-product feeds

A. Cereal by-Products:

Brewer's Dried Grains (BDG): The dried and extracted residue of barley malt alone or in a mixture with other cereal grains or grain by-products resulting from the manufacture of beer. It has a high crude protein content of 16 to 24% of dry matter. It also has a high cellulose content of 9-20% of dry matter. Has about 80% of the energy content of Barley grain but not as palatable as the original grain. Chiefly used interchangeably with other feeds of similar bulk in finishing rations.

Brewer's Dried Yeast (BDY): Is the dried, non-fermentative, non-extracted yeast of the botanical classification *Saccharomyces* resulting as a by-product from the brewing of beer. It contains more than 35% Crude

Protein. It is an excellent source of highly digestible protein of good quality.

Grain Screenings: Consists of 70% or more of light and broken grains along with weed seeds and other foreign material that is separated in the cleaning of grain with a screen. Quality varies according to the percentage of weed seeds and other foreign material. Most grain screenings are incorporated in ruminant rations. Screenings are normally limited to 15 to 20% of feedlot rations.

Wheat Bran: The coarse outer covering of the wheat kernel separated from wheat in commercial milling. It is rich in Niacin, Vitamin B1, P and Fe. A large part of the phosphorus is phytin phosphorus. Widely used in horse rations because of its bulky nature and laxative effects. It is also a favored supplement in sheep rations.

Wheat Middlings: A by-product of the milling industry. It consists of the fine particles of bran, shorts, germ and flour. It should not contain more than 9.5% fiber. But deficient in calcium, carotene and vitamin D. It is widely used as a potential grain replacement in rations for all animal species.

Wheat Shorts: A similar product to wheat bran and middlings but lower in its Crude Fiber content (max. 7%) and richer in its energy composition because it contains the finer wheat milling by-products including a larger proportion of flour.

B. By- Products of Oil Mills:

Cottonseed meal: The finely flaked residue that remains after most of the oil from cottonseed has been extracted. The nutritive value of this meal varies a great deal according to the manufacturing technique used. The Crude Protein content of the decorticated meal can range between 40 and 50%. Cottonseed meal is low in lysine, methionine and tryptophan and deficient in Vitamin D, Carotene and Calcium but rich in Phosphorus. It may contain a toxic material known as Gossypol that can cause pink coloration of the egg white from layers and reduced growth rate in

young chicks. It is an **excellent** protein supplement for **ruminants**, since they can tolerate Gossypol and do not require lysine and tryptophan in the diet.

Groundnut meal (Peanut Meal): Can contain 45 to 50% Crude Protein depending on the method of oil extraction. It is low in methionine, lysine and tryptophan. It is also low in Calcium; Carotene and Vitamin D. Groundnut meal is palatable and contains high quality protein. Groundnut meal is used extensively in livestock and poultry diets. The meal can be contaminated with moulds especially *Asperigillus flavus* that excretes a toxin known as aflatoxin, that is dangerous especially for young poultry. Since this product tends to become rancid when held too long, especially in warm moist climates, it shouldn't be stored for more than six weeks.

Linseed meal (Flax meal): It is low in the amino acids lysine and tryptophan. It is also lacking in Carotene and Vitamin D and only fair in the content of Calcium and B-vitamins.

Noug meal: A product comparable in feeding value to under corticated peanut meal. It is very palatable and can, thus, be included in concentrate mixtures for all classes of livestock. It is rather high in its Crude Fiber content.

Rapeseed meal: May be used as a protein supplement for all classes of livestock. It may be used at maximum levels of 20% in most rations.

Sesame Meal: Has analytical characteristic as similar to groundnut meal. It is a little oilier, richer in Cellulose and a little poorer in total Crude Protein content. Have high methionine content and, thus, an excellent quality plant protein supplement suitable for all animal species. No toxic factor is known in this meal. The color of the expeller meal varies with the variable color of sesame seed varieties.

Soybean meal: It is a product obtained by grinding the flakes that remain after extracting most of the oil from Soybeans. Has the highest nutritive value of any plant protein source. The preponderance of **Soybean meal**

is explained by its richness in the "indispensable" amino acids, notably lysine. The heat treatment of Soybean meal improves its digestibility and destroys the toxic factor, anti-trypsin factor (ATF), of which small amounts are present in crude Soya. Contains 40to 50% Crude Protein, very palatable and, thus, suitable for all animal species.

Sunflower meal: the variation in feeding value is considerable due to differences in Crude Fiber and the method of extraction. It is a suitable protein supplement for all animal species. Crude protein content ranges from 35 to 40%.

D. Sugar Refinery by -Products:

Cane Molasses: is by-product of the manufacture of table sugar from sugarcane. It is a good energy source but low in protein. It is very palatable and an excellent appetizer. It may be fed to any animal species. Molasses is used mostly as a binder to mixed feeds to be pelleted.

2.4 Mineral and vitamin

Appropriate intake of key minerals and vitamins is essential for livestock productivity and health. Many different commercially available mineral and vitamin supplements are marketed to beef cattle producers. Minerals and vitamins account for a very small proportion of daily dry matter intake in livestock diets and can sometimes be overlooked in a herd nutritional program. Although minerals and vitamins are needed as a very small percentage of dietary nutrients, they are very important in livestock nutritional programs for proper animal function, such as bone development, immune function, muscle contractions, and nervous system function. Cattle growth and reproductive performance can be compromised if a good mineral program is not in place.

2.5 Feed Additives

Feed additives are chemical components that are added to a ration in small amounts, to accomplish one or more of the following:

1. Increased intake (which would mean increased performance)
2. Increased gain
3. Increased feed efficiency

Feed additives are products that you will not buy as an individual product, but as part of a pre-mixed feed or supplement. Extreme care needs to be taken when feeding these products.

The most common feed additives:

Antibiotics: Antibiotics are medicine (like you take) that are fed at low levels in a ration to help reduce sickness, and therefore improve animal performance. Common antibiotics are Aureomycin and Terramycin.

Ionophores: Ionophores are feed additives that may improve feed efficiency by 5-10%. The most common examples of ionophores are Rumensin (chemical is monensin) and Bovatec (chemical is lasalocid).

Hormones/Anabolic agents: Anabolic agents are implants that contain steroid hormones that promote growth in cattle. These hormones are similar to the ones that are naturally occurring in the animal's body. These agents stimulate gain (especially lean gain) and common examples are Ralgro and Synovex.

Beta agonists: This is a new class of compounds that have recently been approved to feed to cattle. The only beta agonist approved for cattle is ractopamine (trade name is Optaflexx). These additives alter how the animal's body uses nutrients. As a result, beta agonists promote lean growth.

Supplements

Supplements are feeds which are high in one or more of the nutrients required by animals (with the exception of water). They can be further broken down into protein supplements, energy supplements and vitamin and mineral supplements. Some feeds may fall into more than one category. Many of these feeds are by-products of industries that produce a product destined for human consumption.

Energy Supplements Many energy-rich feeds are by-products of cereal grain milling. These by-product feeds usually come from various layers of the seed covering, which, along with being higher in fibre, are higher in protein and minerals than the seed itself, which is mainly starch. The most common milling by-products are from wheat with lesser amounts derived from corn. These are classified on their fibre content and include bran, middlings, shorts, red dog and wheat-germ meal. In Ontario and Canada, poultry feed is the largest user of these by-products. While much of the starch has been removed, they are still good sources of energy.

Molasses is the major by-product of sugar production, coming mainly from sugar cane but also from sugar beets. Most molasses in commercial use is adjusted to contain 25% water. It may also be dried so that it may be added to dry diets, but this is a much more expensive product. While molasses is a good source of trace minerals, the protein and vitamin level is quite low. It is used often to stimulate eating, to reduce dustiness in feeds, as a pellet binder, and when fortified with an N source, as a ruminant feed known as a liquid protein supplement.

Beet pulp is another by-product of sugar extraction. It may be purchased either flaked or pelleted and may have molasses added to it. It is very palatable and, despite its relatively high fibre level, is quite digestible. It is often used in lactating cow rations to stimulate appetite.

Surplus fats may be fed as an energy source only, since they supply almost no protein, vitamins or minerals. When available at reasonable costs, fats may be used in feeds to decrease dustiness and increase palatability. Since fats are subject to oxidation and rancidity, which will decrease their palatability, antioxidants are usually added. Fats are not often fed to ruminant animals except perhaps in milk replacer formulas and occasionally

in a finishing or lactating cow ration, since ruminants are not tolerant of fat levels higher than 7-8%.

Protein Supplements These may originate from either plant or animal sources, or in the case of ruminants, from non-protein N Sources. A protein supplement is a feed which has more than 20% crude protein. These are usually the most expensive constituents in animal rations so their selection is affected by cost and availability. The content and availability of amino acids for monogastric species, the presence of undesirable or toxic substances and the content of other nutrients should also be considered. Most of the plant protein-rich feeds are by-products of the oil extraction industry, with soybean meal being the most common in Ontario. The protein is usually low in the sulphur containing amino acids cysteine and methionine and may be low in lysine. Soybean meal has a protein level of 44% or 48% depending whether or not the hulls are added back. It is probably the most common protein source in North America and it is quite palatable, highly digestible and has fairly high energy levels.

Canola meal is probably the second most common oilseed meal fed in Ontario, and likely the most common in the Western provinces. It contains between 35% and 40% protein, with slightly less lysine and slightly more methionine than soybean meal. Perhaps the major disadvantages of canola meal are the high fibre levels and resulting lower energy levels for all species and the anti-nutritional factors which may be present. Canola has been bred to be low in the anti-nutritional factors that were previously associated with rapeseed, and most of the new varieties are "double-low". For most animals the best results in growth rate and feed efficiency are obtained when the level of canola meal in the diet is less than 20%.

Cottonseed meal and linseed meal are two other potential feedstuffs, but due to climate and changes in consumer preference very little is fed in

Ontario. Linseed meal, often called oilcake, is a meal made from flax, which is deficient in lysine and is seldom grown in large quantities anymore. It is most popular as a feed for show cattle, since it tends to produce a very glossy hair coat, but it is generally too expensive for the protein it provides to be used commercially.

Other by-products of plant origin are brewer's and distiller's grains. Either can be purchased in the wet state, but since it is more convenient for transportation and storage, they are usually dehydrated. Distiller's dried grains contain 25-30% protein, have relatively high fibre levels and, due to the yeast present, a high B vitamin content. They are often deficient in lysine since they are primarily corn based. Brewer's dried grains have considerably more fibre (18-19%) and as a result are more suitable as a protein supplement for ruminants. The protein level is 25-30% and low in lysine, but high in methionine.

Animal protein supplements (meat meal, blood meal, bone meal) are usually by-products of the meat-packing industry. Since these are animal tissues, the amino acid distribution is usually similar to the animals' requirements, although quality may be quite variable since the composition of the meal may vary from batch to batch.

There are two major types of fishmeals - those made from the waste of fish caught for human consumption and those made from fish caught specifically for industrial use. Fish meal must be dried down to 15% moisture and have the fat content reduced to a maximum of 10%. Antioxidants are always added since the oil oxidizes readily. The protein is very digestible and is very high in lysine, which makes it a good protein source to supplement feed cereal grains. Fishmeal is a good source of the B vitamins, all minerals, and seems to have unidentified growth factors which enhance growth rate and feed conversion in swine.

Single cell protein. Certain bacteria, yeast, fungi and algae can ferment residues from pulp mills, food processing, alcohol production and even human or animal wastes. At the present time, harvesting and dehydration costs are uneconomical, but products resulting from this process can be fed to supply part of the protein requirement for almost all animals without any noticeable decrease in performance. The protein concentrations range from 48-80% and are reasonably well digested. Most contain moderate energy and may provide other nutrients such as the B vitamins. Perhaps as production techniques are refined, costs will decrease and these protein sources will become more competitive with other feedstuffs.

Minerals

Numerous minerals are essential for proper animal nutrition. In addition to their metabolic functions, the macro-minerals are necessary for tissue structure (e.g. calcium and phosphorous in bone or egg shells) and for milk secretion. Plant tissues obviously contain considerable mineral but the actual content can vary with stage of maturity and soil conditions. Feed analysis is necessary to indicate the actual composition so that diets can be fortified as required.

Macro-minerals	Micro-mineral
calcium	iron
phosphorus	copper
sodium	zinc
chlorine	manganese
potassium	cobalt
sulphur	iodine
magnesium	selenium

molybdenum

chromium

Bone meal, limestone and many mineral supplements are available from commercial feed suppliers. Analysis of home grown and purchased feed ingredients will reveal their actual composition. Once this information is available, informed decisions can be made on what additional ingredients will be necessary to balance the diet for various species and production stages.

Some farm animals certainly suffer from mineral deficiencies. However, excess amounts are toxic so conscientious attention to individual requirement and inclusion of the appropriate supplements is necessary to satisfy needs.

Vitamins

Vitamins function as cofactors or enzyme activators in metabolic processes so are necessary for all general body functions and maintenance of health. All green, growing plants contain carotene which animals can convert into vitamin A. Supplemental vitamin A may be necessary to ensure an adequate supply whenever herbivores are not grazing on good quality pasture and for omnivores and carnivores. The rumen micro-organisms produce B vitamins so these are unlikely to be deficient in mature ruminants. In contrast, diets for very young calves and all non-ruminants may require some supplementation with B vitamins. The sun's ultraviolet rays produce vitamin D from the provitamin in the skin and from ergosterol in plants during field curing of hay. Thus, animals spending considerable time outdoors or receiving ample, good quality hay should have sufficient. Animal diets usually contain sufficient vitamins E and K but deficiencies can occur. As with all other nutrients, diets should be designed to meet individual requirements

and fortified to provide a slight excess of any vitamins that could be deficient under natural conditions.

Unconventional feedstuffs

Unconventional feeds are those which are not used for feeding to livestock and poultry routinely or they are not the usual feeds. They become the conventional feeds after investigating on them in terms of their: Availability, Chemical composition, Digestion and absorption and Identifying incriminating factors and detoxification.

Agro-industrial byproducts can be grouped according to the **content of nutrients**:

1. Energy rich supplements e.g. molasses, citrus, reject banana, pine apple waste and cassava byproducts.
2. Protein rich supplements e.g. oil cakes, fish and meat meals, pulse chunnies, animal organic wastes.
3. Byproducts supplying minerals e.g. bone meals, sea weeds etc.
4. Miscellaneous byproducts: supply energy and protein e.g. brewery products, fruit and vegetable industries products.

Grouped on the basis of **their origin**:

1. Agricultural crop residues
2. Byproducts from sugar industry
3. Byproducts from forestry
4. Non-edible and other minor oilseed cakes
5. Fruit and vegetable factory byproducts
6. Marine waste and byproducts
7. Meat processing wastes
8. Animal organic wastes
9. Miscellaneous byproducts.

1. Agricultural crop residues: They include

- 1) Cereal straws: wheat/ barley/ oats/paddy/maize and sorghum stovers etc which are fed as such or after processing (alkali, urea, acids or biological

treatments). Processing increases the nutritive value of these straws substantially.

2) Pulse straws: They mostly of dicot pulses like Urad (*Phaseolus radiates*), Moong (*P. mungo*), Moth (*P.aconitifolium*), Cow pea (*Vigna catiang*), Masoor (*Lens esculenta*) and Arhar (*Cajanus indicus*). After removing seeds, the remaining parts like pod husk, leaves and tender stems are utilized to formulate the nutritious feeds. They are good protein straws.

3) Groundnut straw: The ratio of tops to nuts is 1: 0.75. A ration containing GN straw, wheat bran and wheat straw is able to sustain 5 kg milk production per day. It has good DCP values than non-legume hays and comparable with legume hays.

4) Rape straw: It has poor nutritive value and animals normally do not eat. It is used as fuel in maturing the bricks.

5) Husks:

A) Rice husk: contains water- 8-11, ash- 15.6-22.6, AIA- 14.5-17.5, CP- 3-3.6, EE- 0.8-1.2, NFE- 25-29 and CF- 39-42%. It is not palatable. Alkali treatment improves the nutritive value but economics is to taken into account. It can be used as bedding materials for poultry and animals, as fuel for bricks and production of furfural etc.

B) Groundnut husk: It is unpalatable to cattle and poorer in nutritive value than rice husk.

C) Maize husk: Superior to gram hush in nutritive value. 50% of dry roughage portion in the rations of adult non-producing cattle can be replaced by maize husk.

2) Sugar industry byproducts: They are sugarcane tops, bagasse, molasses, press mud and condensed molasses soluble.

i) Sugarcane tops: They are palatable due to its sugar juice. Can maintain cattle on tops and little protein supplements. Good quality of silage can be prepared, for example Japan imports lot of cane tops silage from Philippine for its animals.

ii) Bagasse: It is used as fuel in boilers of sugar industry, manufacture of pulp and papers and production of furfural. The bagasse is a good source of cellulose but poor in protein (1.3%) and high in lignin (16%). It can be fed either treated or non-treated to ruminants.

iii) Molasses: contains 50% sugar, water-20.6, total sugar-60.8, CP-3.2, soluble gum-2.2 and ash-8.2%. The molasses is used as carrier for urea impregnation of poor quality roughages like wheat/paddy/bagasse etc as binder for commercial pelleted feeds like uromol and for increasing the voluntary intake of feeds. It can be added in the ration from 5-10%.

iv) Press mud: Press mud is obtained during process of precipitation of sugar. It is used for extraction of wax. Contains organic matter- 64% of dry weight and rich in calcium. No work has been done on press mud as feed for animals as it contains lot of sand.

v) Condensed molasses soluble/ dried yeast sludge: These are the byproducts of fermentation processes for production of alcohol, yeast, citric acid, monosodium glutamate etc. after condensation to 65-75% dry matter, it is called as condensed molasses soluble. Whereas after fermentation of molasses to alcohol it is called as yeast sludge. Yeast sludge is used in poultry upto 20% in the diet.

3) Byproducts from the forest: They include fodder trees, leaves, pods and seeds etc.

Fodder tree leaves: The fodder tree leaves can be used to ameliorate fodder scarcity problem. The tree leaves, tender shoots and twigs are consumed by cattle, sheep, goat, camel and elephants etc. In many parts, concentrate is rarely fed and the animals meet the requirements of growth and lactation only from the tree leaves. Tree leaves contain DM-30-45%, CP- quite high, CF-complex and lignified, Ca- high (2-3 times higher than cultivated fodders), P- low so wide Ca: P ratio.

a) Ardu leaves (Alanthus excels roxes): A full grown tree gives about 6-7 Q of edible leaves, twice in year. The leaves contain 13% DCP and 63%

TDN. It has experimentally shown that adult animals can be maintained on these leaves.

b) Bambo leaves (*Dendrocalmins strictus*): These leaves become available when the bamboo plants are cut or harvested for the purpose of paper manufacturing. One hectare of bamboo forest gives 90-150 tonnes of leaves. The bamboo leaves contain 9.4 % DCP and 49% TDN. The leaves contain the oestrogenic factor.

c) Beri leaves (*Zizyphus jujube*): These leaves are eaten by sheep, goats and camels. In scarcity of fodders the large animals like cattle and buffalos also eat these leaves. They contain 8.6% CP; the digestibility (36%) is poor due to presence of tannins.

d) Mulberry leaves (*Morus indica*): The mulberry leaves and stalks are available when branches cut for the harvest of silk worms. The leaves are highly palatable and the feed intake is 3.4% of the body weight in sheep. The leaves contain about 11.4% crude protein. The nutritive value of leaves is – 7.8% DCP and 48.4% TDN.

e) Neem leaves (*Azadirachta indica*): This plant remains green throughout year and drought resistant. The leaves are not relished by the animals. Buffaloes consume about 4-6 kg/day and goats also consume good quantity. It contains 6.2% DCP and 52.5% TDN.

f) Pipal leaves (*Ficus religiosa*): This plant remains green throughout the year. The palatability of leaves is not very good for cattle. Goats relish the leaves. The dry matter intake is 2.4 kg/100 kg body weight in goats and 0.9 kg/100 kg body weight in cattle. The leaves can serve as maintenance ration for goats.

g) Tapioca leaves (*Manihot utilissmia*): Their nutritive value is 8.3% DCP and 45.5% TDN. It has been shown that in growing calves, 2.3 kg of partially dried leaves can replace 0.7 kg of groundnut cake. It contains 7.6 mg HCN/100 g material.

4. Non-edible and other minor oilseed cakes:

A) Sal (*Shorea robusta*): This tree is found in Himalayan forest and from the forest about 55 million tonnes of sal kernel and from the kernel about 6 million tonnes of fat is available. This oil is used in confectionary industry and large quantities of deoiled sal seed meal is available for livestock feeding. The sal seed meal contains 7% CP, but the digestibility of protein is negligible so this is only source of energy. The TDN is also low (45%) and is equal to the wheat straw. Sal seed meal contains high tannins (8-13%). It has been demonstrated that the sal seed meal can be fed to growing and lactating animals only upto 10% in the diet. Sal seed meal be treated with hot water and about 34.6% of tannins are removed from it, with the recovery of 94% dry matter. The treated meal may be fed to grower and layers birds to the extent of 5-10%. In pigs by feeding sal seed meal, the growth rate is not affected but the feed efficiency was depressed, when maize was replaced with it.

B) Neem cake (*Azadirachta indica*): The neem seed cake is obtained after extraction of oil from the seeds. This oil is used in soap industry. In India about 75,000 tonnes of deoiled neem seed cake was available in the year 1976. The cake contains about 11.2 – 25.4% CP. The cake is bitter in taste and not palatable. The nutritive value of the cake is 8.4% DCP and 57.8% TDN. Inclusion of 10% cake in the concentrate mixture depressed growth rate in calves. The bitterness of the cake can be removed by alkali treatment. The treated cake becomes palatable for cross-bred calves when included at 50% level of concentrate mixture, but the growth rate was inferior to that of control group. The water treatment of the cake improved its palatability and nutritive value.

C) Mahua cake (*Madhuca indica*): In India the annual production of mahua seeds is about 2175 thousand tonnes and out of this only 20% of seeds are collected from the forest for the purpose of extraction of oil. The cake contains the saponin which is known as mowrine, due to which it is not palatable. The cake contains about 14% CP and 2% mowrine. Steeping in water for 2 hours, made the cake palatable and 10-25% level can be

included in concentrate mixture. The nutritive value of the cake is 8.6% DCP and 45.5% TDN. Long time feeding showed degenerative changes in liver and kidneys in sheep.

D) Rubber seed cake (*Hevea brasiliensis*): In Kerala state of India about 150 thousands tonnes of rubber seed cake is produced after extraction of oil from the seeds. In seeds about 25% oil is present. The nutritive value in cattle was found to be 18.6% DCP and 54% TDN. The cake can be used at 20% level in the concentrate mixture. The cake can also be fed to poultry, pigs and cattle but not to breeding hens, as it affects the hatchability negatively.

5. Fruit and vegetable industry byproducts: Byproducts from these industries available are from mango, pine apple, oranges, limes, lemon, guava, banana, green peas, tomatoes, potatoes and mushrooms. But the problem is that they contain high water contents and makes the transportation difficult.

a) Mango seed kernel/cake (*Mangifera indica*): The byproducts or wastes are available after consumption of fruits by human beings and after preparation of jam and pickles. Extensive research was conducted on utilization of mango seed kernels as livestock feeds in India. It contains 6% DCP and 70% TDN. It is also rich in tannins (5-7%). It can be used upto 40% in concentrate mixture without any ill effect on adult bullocks. The cake is available after extraction of oil from the seed or kernels, which can be fed to animals.

b) Tomato pomace: The tomato pomace consists of skin, pulp and seeds. It can be used after drying as good feed ingredient. It contains 1.43% DCP and 41% TDN. The dried pomace can be added upto 1/3 rd of concentrate or can replace wheat bran on weight basis.

c) Citrus peels: Dried and ground citrus oranges and lemon peels can be used as one of the ingredients of the concentrate mixtures. Citrus peels can be included at 33% in the concentrate mixtures.

d) Pine apple waste: The pine apple waste consists of peels, pomace and leaves. In Philippines, 5000 feed lot beef cattle are raised on the fresh and ensiled pine apple wastes. It has been observed that when 10% concentrate and 90% waste material fed to growing steers, a growth rate of 600-700 g/day was achieved.

6. Marine wastes and byproducts: They include the waste material available from the fishing and fish processing industries. The fish meal contains 60% CP and is normally fed to monogastric and the young calves, but acid insoluble ash content is high. The fish wastes can be used to prepare the silage and be fed to ruminants.

Sea food canning industry wastes are shells of prawns and shrimps. Processed shrimp meal has 47% CP and 27% ash. The other wastes/byproducts are prawn shell, head wastes, lobster waste, frog waste, shark liver residues etc. The frog meal contains 60% CP and can replace the fish meal in the diets of poultry for growth and eggs production.

Sea weeds are marine algae, which may be green, brown, red and blue color. Sea weeds are the sources of agar-agar and algin and contain 16-30% CP. Byproducts of algae are used as cattle feed. They are the good sources of minerals to the livestock.

7. Meat processing wastes:

A).Tankage: Tankage is a good protein supplement for swine but sheep and cattle do not like it.

B) Meat scrap: Mostly used as protein supplement in poultry feeds.

C) Blood meal: contains 80% CP but poor in ca & P. It is unpalatable for animals.

D) Feather meal: can be added only after proper processing. It can be added in the ration of broilers at 25% level. It contains B12 and two unidentified vitamins for chick growth.

These wastes should be fed only after proper processing to avoid the contaminations from different organisms.

8. Animal organic wastes: These wastes include excreta from cattle, buffalo, sheep, goats and poultry. They are rich in protein, Ca, P and minerals, contain 25% CP and can be added 50% in concentrate mixtures of ruminants. Good silage can be prepared from mixing 40 parts of poultry litter, 50 parts of green chaffed maize and 10 parts of molasses. It has been observed that dried cattle or buffalo excreta can be incorporated in the concentrate mixture for maintenance adult animals, whereas it can be fed at 20% level in growing calves without any deleterious effects. Care should be taken these wastes are free from any pathogenic organisms and residues of drugs.

9. Miscellaneous byproducts:

a) Malt industry wastes: They include brewer's grains, liquid sludge obtained after fermentation of substrates and brewer's yeast etc. Dried brewer's yeast is marketed for poultry feeding. They are rich in vitamins except B12. Brewer's grains are fed to dairy and feed lot cattle.

b) Silk worm pupae meal: Silk worm pupae are available after manufacture of silk threads. It contains 55% CP and 25-27% oil. It is a good source of protein for poultry. Tusser silk worm pupae meal contains about 65.6% CP and used as component of livestock rations.

c) Maize gluten meal: It is obtained after removal of starch and germ from the maize. It contains 40-48% CP and fed to poultry and cattle as protein supplement.

d) Tapioca wastes: Obtained during extraction of starch from tapioca roots. It serves as good energy source as it contains 64% TDN and 2.0 % CP and used in the rations of growing and lactating animals.

e) Oak kernel: They are available from oak tree. It can be used in poultry and cattle rations. In hills it is used for feeding small ruminants.

f) Babool pods (*Acacia Arabica*): They can be fed to small ruminants and cattle either ground or unground forms as component of concentrate mixture. They contain 5.73% DCP and 62.5% TDN.

g) Tea industry wastes: The tea wastes are available in the form of fluffs, stalks and sweeping. Tea leaves residue obtained after isolation of caffeine is

used as feed ingredient. It contains 18% CP. Spent tea leaves contain 25% CP and can be used at 20% level in dry state in the concentrate mixture.

h) Dried cocoa pod husk: Contains 6% CP, 31% CF, 12% ash and 16% fat. It can be used up to 10-15% in diets of ruminants. It can also be used in the diets of poultry, pigs, sheep and goats. It contains alkaloid known as thiobromine, produced by quick fermentation; so proper sun drying prevents the production of this factor.

i) Oil palm byproducts: Include palm press, fiber, palm oil sludge and palm kernel cake. Palm oil sludge can be used up to 10% in the ration of cattle and pigs. Palm kernel cake is like rice bran and supplying protein and energy.

3. Classification of basic nutrients

Nutrient is any substance absorbed by an organism from its external environment and used in the metabolism. It is source of materials needed for growth, maintenance, reproduction and production purpose. It includes: Water, Carbohydrate, Proteins, Lipids, Minerals and Vitamin.

a) Water - Often overlooked and not considered as a nutrient when formulating diets for animals, but extremely important.

b) Carbohydrates - Definition? Hydrates of carbon formed by combining CO₂ & H₂O (photosynthesis). The primary component found in animal feeds.

c) Protein - Found in the highest concentration of any nutrient (except water) in all living organisms and animals. All cells synthesize proteins, and life could not exist without protein synthesis.

d) Lipids - Organic compounds that are characterized by the fact that they are insoluble in water, but soluble in organic solvent (benzene, ether, etc.)

e) Minerals - Inorganic, solid, crystalline chemical elements that cannot be decomposed or synthesized by chemical reactions.

f) Vitamins - Organic substances that are required by animal tissues in very small amounts. The last group of dietary essentials to be recognized.

3.1. Water

It is vital to the life of the organism that the water content of the body be maintained. An animal will die more rapidly if deprived of water than if deprived of food. Water functions in the body as a solvent in which nutrients are transported about the body and in which waste products are excreted. Many of the chemical reactions brought about by enzymes take place in solution and involve hydrolysis. Because of the high specific heat of water, large changes in heat production can take place within the animal with very little alteration in body temperature. Water also has a high latent heat of evaporation, and its evaporation from the lungs and skin gives it a further role in the regulation of body temperature.

The animal obtains its water from three sources: drinking water, water present in its food, and metabolic water, this last being formed during metabolism by the oxidation of hydrogen-containing organic nutrients. The water content of foods is variable and can range from as little as 60 g/kg in concentrates to over 900 g/kg in some root crops. Because of this great

variation in water content, the composition of foods is often expressed on a dry matter basis, which allows a more valid comparison of nutrient content.

The water content of growing plants is related to the stage of growth, being greater in younger plants than in older plants. In temperate climates the acquisition of drinking water is not usually a problem and animals are provided with a continuous supply. There is no evidence that under normal conditions an excess of drinking water is harmful, and animals normally drink what they require.

Body water

Water content of the animal body varies considerably; the newborn animal contains 750–800 g/kg water but this falls to about 500 g/kg in the mature fat animal. It is influenced over the long term by the age of the animal and the amount of fat in the tissues. Water content is highest in fetuses and in newborn animals. When body water is expressed on the basis of the fat-free body, the water content is relatively constant for many different animal species.

- The range is from 70–75 % of fat free weight, with an average of about 73%
- Composition animal body can be estimated if either the fat or water content is known
- $\text{Percent Fat} = 100 - \% \text{ of water} / 0.732$.
- Variations in water intake and excretion largely control osmoconcentration.
- Flow of water between the extracellular and intracellular fluids also is important in maintain osmoconcentration.

Water and body temperature regulation

- High specific heat, high thermal conductivity and high latent heat of vaporizations allows:
 - accumulation of heat
 - ready transfer of heat and

- loss of large amounts of heat on vaporization
- These physical properties of water are enhanced by physiological characteristics of animals.

Many animals rely on the cooling capacity of water as it gives up its latent heat during evaporation by panting or sweating.

Animals' heat exchange is efficient i.e.

- ✓ As 1 g of water changes from liquid to vapor, it takes up about 580 Cal of heat but
- ✓ To heat 1 g of water from freezing to boiling requires only 117 Cal

Water Requirement

- The regulation of drinking is a highly complex physiological process. It is induced as a result of dehydration of body tissues.
- However, drinking may also occur when there is no apparent need to rehydrate tissues
- Dogs with esophageal fistula, sham-drinking.
- There is ample evidence that passage of water through the mouth is required for a feeling of satiety.

Most domestic animals generally drink during or soon after eating periods if water is close at hand. In very general terms animals will consume 2 to 5 kg of water for every kg of dry feed consumed when they are not heat stressed.

Young animals generally require more water per unit of body weight than adult animals. Activity increases requirements; nervous animals also will likely consume more water than less active animals.

- ✓ Physiological, dietary, and environmental factors affecting absorption and excretion alter water requirements.
- ✓ Pregnancy also increases the need for water, and animals with multiple fetuses require more water than those bearing singles.
- ✓ Swine generally consume 2 to 2.5 kg of water/kg of dry feed at moderate temperatures.

- ✓ Horses and poultry consume 2 to 3 kg/kg of dry feed.

Water Quality

Water quality may affect feed consumption directly because low quality water normally will result in reduced water consumption and, hence, lower feed consumption and production. Substances that may reduce palatability of water include various salts, and toxic Substances that may be toxic without much effect on palatability include nitrates, fluoride, and salts of some heavy metals. Other materials that may affect palatability or be toxic include pathogenic microorganisms (bacteria, protozoa, and fungi), algae, hydrocarbons and other oily substances, pesticides and many industrial chemicals that sometimes pollute water supply

3.2. Carbohydrates

Carbohydrates (also called saccharides) are—on the basis of mass—the most abundant class of biological molecules on Earth. Carbohydrates consumed by animals serves as source of energy, as a reserve in the form of fat mainly, and also glycogen into which it is readily transformed.

Functions of Carbohydrates in genera

1. Carbohydrates are the main sources of energy in the body.
2. Store energy (starch and glycogen).
3. Excess carbohydrate is converted to fat.
4. Carbohydrates are linked to many proteins and lipids, where they play key roles in mediating interactions among cells and interactions between cells and other elements in the cellular environment.
5. Structural basis of many organisms: Cellulose of plants; exoskeleton of insects, cell wall of microorganisms, mucopolysaccharides as ground substance in higher organisms.

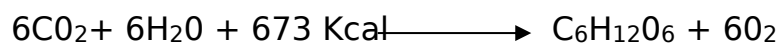
6. Acts as cell surface marker.

7. Ribose and deoxyribose sugars form part of the structural framework of RNA and DNA.

When one sees the carbohydrate in plant tissues, basically they are found in two forms.

i) Structural carbohydrate- mainly cellulose, in terms of quantity cellulose comprise the largest proportion of carbohydrates in plants.

ii) Reserve carbohydrate- starch is the basic reserve carbohydrates while glycogen is for animals. This reserve carbohydrate is main reserve material in most plants but in some plants reserve is kept in the form of fat or oils than carbohydrate like in oil bearing seeds such as nut, peanut. Starch is for cereals mostly. So carbohydrates are the largest part of the animals feed supply. The overall reactions process is represented as:



Glucose is the basic building structure for forming complex carbohydrates. In this way plants store the energy of the sun in products that can be use by animals as a source of energy for life processes. Thus all animal life is dependent upon the process of photosynthesis.

The name carbohydrates owe their name to the fact that they contains carbon combined with H₂ and O₂ often in the same ratio as in water and it means hydrated carbon meaning C atom with H₂O molecule. While a reasonable generalisation, this actually is imprecise definition; although

many carbohydrates have the same empirical formula $(CH_2O)_n$ where $n \geq 3$, the definition is not strictly correct, and there are exceptions for this definition. This includes:

- a) It is possible that other chemical compounds which are not carbohydrates could have the same ratio of the elements C, H, O.

Example: Acetic acid is not CH_2O but has a formula of $C_2H_4O_2$

Lactic acid $C_3H_6O_3$ ($CH_3.CHOH.COOH$)

- b) There is a possibility of the carbohydrate without having the elements in the indicated ratio

Example: Rhamnose $C_6H_{12}O_5$

Deoxyribose $C_5H_{10}O_4$

In nature carbohydrates are designed to foster plant existence, their use as an animal feed is purely incidental. The more soluble forms serve in plants systems in energy transformation and for tissue synthesis, the less soluble ones such as starch serve as a reserve energy, while the relatively insoluble fraction cellulose, hemicellulose form plant structural entities.

Classification of carbohydrates

Carbohydrates are usually divided into 2 major groups according to their chemical nature.

1. Sugars
2. Non- sugar

1. Sugar

These are group of carbohydrates containing less than 10 monosaccharide residues. These are groups of carbohydrates which are soluble in water and sweet to test. These things differentiate sugars from non-sugars which contain >10 monosaccharides units, in their structure; insoluble in water and not show sweet taste.

The sugars include:-

A. Monosaccharides

These are the simplest sugar and are building block of carbohydrates. This could be divided based on the number of carbon atoms present in the molecule as:

- ❖ Trioses ($C_3H_6O_3$)- smallest monosaccharides which contain 3 carbon atoms
- ❖ Tetroses ($C_4H_8O_4$)- contain 4 carbon atoms
- ❖ Pentoses ($C_5H_{10}O_5$)- contain 5 carbon atoms
- ❖ Hexoses ($C_6H_{12}O_6$)- contains 6 carbon atoms
- ❖ Heptoses ($C_7H_{14}O_7$) - contains 7 carbon atoms

The trioses and tetroses occur as intermediates in the metabolism of other carbohydrates. Monosaccharides may be linked together, with the elimination of one molecule of water at each linkage, to produce di, tri-, or tetra- or polysaccharides containing two, three, four or many monosaccharide units respectively.

B. Oligosaccharides

The name comes from Greek oligos means a few and is frequently used to include all sugars other than the monosaccharides. Oligosaccharides contain carbohydrates containing 2-10 monosaccharide units. Oligosaccharides could be divided into different groups based on the number of monosaccharide units as opposed to the number of carbon atom as in the case of monosaccharides.

Disaccharides - oligosaccharides with 2 monosaccharide units

Trisaccharides - oligosaccharides with 3 monosaccharide units

Tetrasccharides - oligosaccharides with 4 monosaccharide units

2. Non-sugars

These contain greater than 10 monosaccharide units. Sugars have less molecular weight than non-sugars. The non-sugars are also called polysaccharides or glycans -(poly means many). So they are polymers of

monosaccharide units. We have two groups of polysaccharides based on the type of monosaccharide units present in the chain.

a. Homopolysaccharides (Homoglycans)

Homo means same, hence these are polysaccharides which contain only a single type of monosaccharide units or these polysaccharides result to one type of monosaccharide on hydrolysis.

Example, Glucans (glucosan) - homopolysaccharides made of many glucose units attached together like Starch, glycogen, cellulose, dextrans, Fructans (Fructosan)- made up of many fructose units like inulin, levan

b. Heteropolysaccharides (Heteroglycans)

All polysaccharides which on hydrolysis yield mixture of monosaccharides. Therefore, these polysaccharides are made of greater than one type of monosaccharides.

Non-sugars also contain complex carbohydrates which are **ill-defined** group of compounds which contain carbohydrates in combination with non-carbohydrates molecules. They include the glycolipids and glycoproteins.

3.2. Proteins

Proteins are complex organic compounds of high molecular weight. Proteins are found in all living cells, where they are intimately connected with all phases of activity that constitute the life of the cell. Each species has its own specific proteins, and a single organism has many different proteins in its cells and tissues. It follows therefore that a large number of proteins occur in nature.

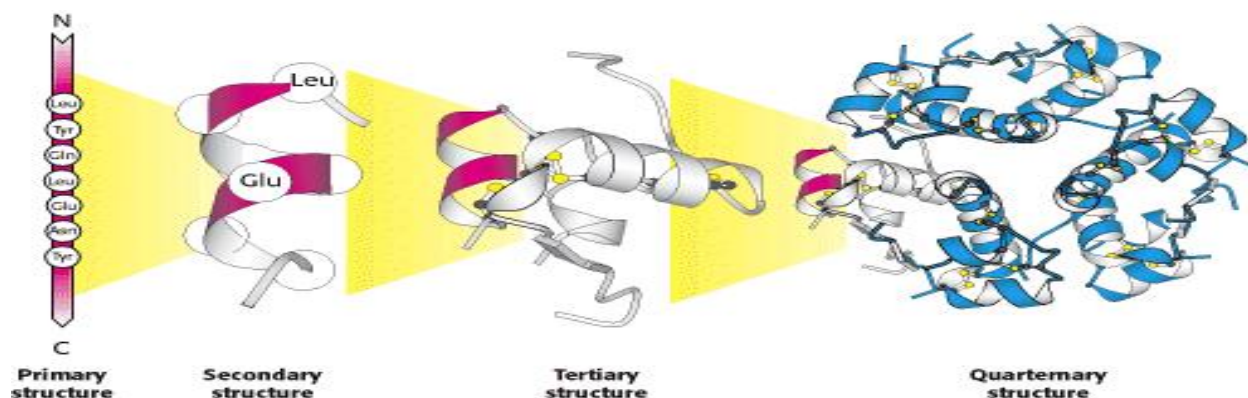
Plant proteins differ from each other and from animal proteins. In **fact** no two proteins seem to be **exactly** alike in their physiological behaviour. From the standpoint of nutrition the important distinguishing feature of the various proteins is their amino acid makeup. Proteins are basically made of building blocks called amino acids, which is one structurally unifying factor of proteins. Proteins are mainly found in active tissues in plants and animals like leaves, shoots, and muscle. In common with carbohydrates proteins contain carbon,

hydrogen and oxygen but in addition they also contain nitrogen. Most proteins also contain sulfur and a few contains phosphorous and iron. In terms of composition of these different elements, they account the following percentages:

<u>Element</u>	<u>Percentage</u>
Carbon	51.0 - 55.0
Hydrogen	6.5 - 7.3
Oxygen	21.5 - 23.5
Nitrogen	15.5 - 18.0
Sulfur	0.5 - 2.0
Phosphorous	0.0 - 1.5
Iron	-

Structure of proteins

The sequence of amino acids along the polypeptide chain of a protein is called the primary structure of the protein. The secondary structure of proteins refers to the conformation of the chain of amino acids resulting from the formation of hydrogen bonds between the imino and carbonyl groups of adjacent amino acids. Folding of the chain gives the tertiary structure. The quaternary structure refers to the configuration of those proteins with more than one polypeptide chain.



Classification of proteins

Proteins may be classified into two main groups: simple proteins and conjugated proteins.

1. Simple proteins

These proteins produce only amino acids on hydrolysis. They are subdivided into two groups, fibrous and globular proteins, according to shape, solubility and chemical composition.

A. Fibrous proteins

These proteins, which in most cases have structural roles in animal cells and tissues, are insoluble and are very resistant to animal digestive enzymes. They are composed of elongated filamentous chains joined together by cross-linkages. The group includes collagens, elastin and keratins.

Collagens are the main proteins of connective tissues and constitute about 30 per cent of the total proteins in the mammalian body.

Elastin is the protein found in elastic tissues such as tendons and arteries. The polypeptide chain of elastin is rich in alanine and glycine and is very flexible. It contains cross-links involving lysine side chains, which prevent the protein from extending excessively under tension and allow it to return to its normal length when tension is removed.

Keratins are classified into two types. The α -keratins are the main proteins of wool and hair. The β -keratins occur in feathers, skin, beaks and scales of most birds and reptiles. These proteins are very rich in the sulphur-containing amino acid cysteine; wool protein, for example, contains about 4 per cent of sulphur.

B. Globular proteins

Globular proteins are so called because their polypeptide chains are folded into compact structures. The group includes all the enzymes, antigens and those hormones that are proteins. Its first subgroup, albumins, are water-soluble and heat-coagulable and occur in milk, the blood, eggs and many

plants. Histones are basic proteins that occur in cell nuclei, where they are associated with DNA. They are soluble in salt solutions, are not heat-coagulable, and on hydrolysis yield large quantities of arginine and lysine. Protamines are basic proteins of relatively low molecular weight, which are associated with nucleic acids and are found in large quantities in the mature male germ cells of vertebrates. Protamines are rich in arginine but contain no tyrosine, tryptophan or sulphur-containing amino acids. Globulins occur in milk, eggs and blood, and are the main reserve protein in many seeds.

2. Conjugated proteins

Conjugated proteins contain, in addition to amino acids, a non-protein moiety termed a prosthetic group. Some important examples of conjugated proteins are glycoproteins, lipoproteins, phosphoproteins and chromoproteins.

Glycoproteins are proteins with one or more heteroglycans as prosthetic groups. In most glycoproteins the heteroglycans contain a hexosamine, either glucosamine or galactosamine or both; in addition, galactose and mannose may also be present. Glycoproteins are components of mucous secretions, which act as lubricants in many parts of the body.

The storage protein in egg white, ovalbumin, is a glycoprotein. Lipoproteins, which are proteins conjugated with lipids such as triacylglycerols and cholesterol, are the main components of cell membranes and are also the form in which lipids are transported in the bloodstream to tissues, either for oxidation or for energy storage. They can be classified into five main categories in increasing order of density: chylomicrons, very-low-density lipoproteins (VLDL), low-density lipoproteins (LDL), intermediate-density lipoproteins (IDL) and high-density lipoproteins (HDL). Phosphoproteins, which contain phosphoric acid as the prosthetic group, include the caseins of milk and phosvitin in egg yolk.

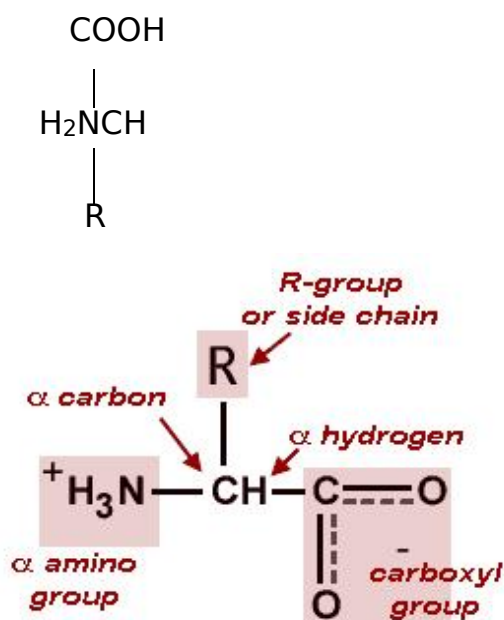
Chromoproteins contain a pigment as the prosthetic group. Examples are haemoglobin and cytochromes, in which the prosthetic group is the iron-containing compound haem, and flavoproteins, which contain flavins.

Amino acids

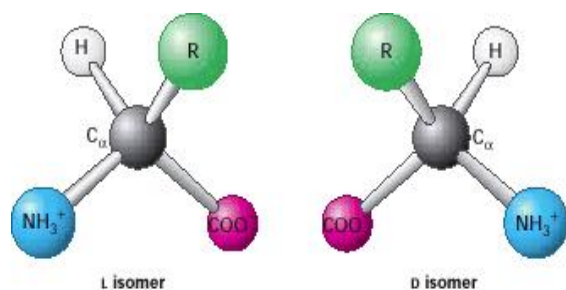
Proteins are polymers of amino acids. Amino acids are produced as hydrolytic end products, where proteins are heated with strong acids, alkalis or when they are acted upon by certain enzymes.

There are a number of amino acids identified the highest figure mentioned in books is 200 amino acids. Out of these only 20 amino acids are commonly found as components of proteins and hence nutritionally important.

Amino acid are characterised by having a basic nitrogenous group, generally an amino group (-NH₂), and an acidic carboxyl group (-COOH). Most amino acids occurring naturally in proteins are of the α type, having the amino group attached to the carbon atom adjacent to the carboxyl group and can be represented with the general formula.



L- amino acid



The difference in different amino acids is in the side chain R. In nature the amino acids usually assume the L- configuration and hence this form is important. There is a possibility of manufacturing amino acids in the laboratory both the L and D form. When we supply both forms to animals only the L form is utilised for protein synthesis as this is similar to the one in nature.

Amino acids by virtue of having an amino and carboxyl group, they show different characteristics in different medium solutions. They assume acidic or basic properties depending on the pH medium. In acidic pH show basic characteristics (amino acid is a cation) and in basic medium show acidic characteristics (amino acid is an anion), and at a pH it is electrically neutral amino acid is dipolar. Such characteristic is called amphotericism. Because of this amphoteric nature amino acids act as buffers, resisting changes in pH.

To study the different amino acids that constitute the different proteins classification is developed where by amino acids are divided into 3 groups depending on their chemical structure or a series of organic compounds in which they belong.

I. Aliphatic amino acids - these contain straight chain amino acid.

II. **Aromatic** amino acids - these are amino acids containing benzene ring somewhere in their structure. Example, phenylalanine, tyrosine, diiodotyrosine, thyroxine.

III. Heterocyclic amino acids - are amino acids not fit in any one above. Example, Histidine, proline, hydroxyproline, tryptophan.

Aliphatic amino acids are the amino acids which contain most of the nutritionally important amino acids. These group can be subdivided into:

- A. Neutral amino acids - are amino acids which contain equal no of the amino and carboxylic group. Since this group contain one NH_2 & one COOH , they are called monoamino-monocarboxylic acids. This comprises the largest number of amino acids. Example, glycine, alanine, serine, valine, leucine. isoleucine and threonine.
- B. Acidic amino acids (monoamino-dicarboxylic acids)- These are amino acids that contain more number of carboxylic than amino group and hence the acidic properly is more. Example, Aspartic acid, glutamic acid.
- C. Basic amino acids (Diamino-monocarboxylic acids) - These amino acids has more amino than carboxylic group and hence dominant basic character. Example, Arginine. Lusine. Citrulline.
- D. Thio amino acids - these are sulfur containing amino acids like cysteine, cystine, methionine.

Plants and many microorganisms are able to synthesise proteins from simple nitrogenous compounds such as nitrates, so can synthesise all the 20 amino acids. Animals cannot synthesise the amino group. So in order to build up proteins a dietary source of amino acids is essential. Certain amino acids could be synthesised in the animal body from others while a number of them cannot be synthesised in the animal body and these are referred to as indispensable or essential amino acids, so must be included in the diet. The others which are not obligatory and can be synthesised within the body are called dispensable or non-essential amino acids.

From works done on rats, monogastric animals require the following ten essential amino acids.

Phenylalanine	Valine	Threonine
Tryptophan	Isoleucine	Methionine

Histidine Arginine Leucine Lysine

The chicks require in their diet the ten amino acids plus glycine as the 11th essential amino acid. To easily remember, one may use the abbreviation **PVT TIM HALL** + **G** (for poultry), where each letter represents the 1st letter of the respective essential amino acid.

Dispensable amino acids include:

Cysteine Tyrosine Glutamic acid Alanine Aspartic acid
Serine Proline Cystine Citrulline Hydroxyproline

In the case of ruminants, all the indispensable amino acids can be synthesised by the rumen microbes, which theoretically make these class of animal independent of a dietary source for essential amino acids. The exception is for high producing animals, supplementation of good protein feeds may be essential to meet the demand for their high production of animal products.

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 by this means, with the elimination of one molecule of water at each linkage, to produce polypeptides. Besides being important building blocks in the construction of proteins, some peptides possess their own biological activity. Milk, in particular, is a source of many biologically active peptides.

The enzymatic hydrolysis of the milk protein casein releases opioid peptides, which have pharmacological activities such as analgesia and sleep-inducing effects. Other peptides derived from casein are involved in calcium flow in

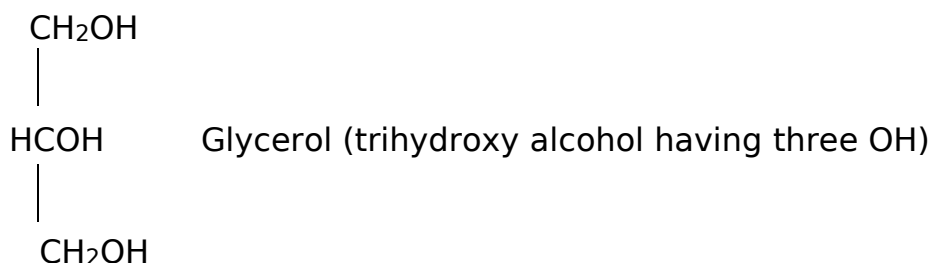
tissues and modification of the immune system response. Other milk peptides stimulate growth of desirable bacteria and suppress harmful bacteria, and some act as growth factors for intestinal cells. Other peptides, including bombesin, enterostatin, glucagon and leptin, are important in the control of food intake. Peptides play an important role in the flavour and sensory properties of foods such as yeast extract, cheese and fruit juices.

3.4. Lipids

Lipids are group of substances found in plant and animal tissues, insoluble in water but soluble in common organic solvents such as benzene, ether, chloroform, ethanol which is the specific character of lipids. These are basically made up of the elements carbon, hydrogen and oxygen, but quantity of oxygen found in basic lipid structures is lower than that found in carbohydrates.

Lipids can be divided into two basic groups

1. Glycerol based lipids: are lipids having glycerol unit in their structure while



2. Non glycerol based lipids: are lipids that do not contain glycerol in their structure.

Glycerol based lipids are divided further into:

- a. Simple lipids: these have one group of compounds that is fat & oils.
- b. Compounds lipids: these are of two types
 - i. Glycolipids: are lipids that contain sugar attached to the lipid molecule. It can be glucolipids that contain glucose attached to the lipid or galactolipids that contain galactose attached to lipid molecule.

- ii. Phospholipids: are lipids containing phosphoric acid or phosphorous attached and are of two types, lecithins and cephalins.

Lipids play different roles in the animal body. They act as electron carriers, substrate carriers in enzymatic reaction, as components of biological membranes & stores of energy.

Additional Functions of Lipids

- ✓ As an energy source, lipids provide 9 kcal of energy per gram.
- ✓ Triglycerides provide energy storage in adipocytes.
- ✓ Phosphoglycerides, sphingolipids, and steroids are structural components of cell membranes.
- ✓ Source of steroid hormones are critical intercellular messengers.
- ✓ Helps in absorption of lipid-soluble vitamins (A, D,E, K)
- ✓ Provide shock absorption.
- ✓ Helps in insulation to heat change.
- ✓ Adds taste & palatability to foods.
- ✓ Acts as surfactant, detergent & emulsifying agent.
- ✓ Give shape to the body.

Plant lipids are of two main types: structural and storage. The structural lipids are present as constituents of various membranes and protective surface layers and make up about 7 per cent of the leaves of higher plants. The surface lipids are mainly waxes, with relatively minor contributions from long-chain hydrocarbons, fatty acids and cutin. The membrane lipids, present in mitochondria, the endoplasmic reticulum and the plasma membranes, are mainly glycolipids (40–50 per cent) and phosphoglycerides. Plant storage lipids occur in fruits and seeds and are, predominantly, triacylglycerols.

In animals, lipids are the major form of energy storage, mainly as fat, which may constitute up to 97 per cent of the adipose tissue of obese animals. The

yield of energy from the complete oxidation of fat is about 39 MJ/kg DM compared with about 17 MJ/kg DM from glycogen, the major carbohydrate form of stored energy. In addition, stored fat is almost anhydrous, whereas stored glycogen is highly hydrated. Weight for weight, fat is, therefore, about six times as effective as glycogen as a stored energy source. The structural lipids of animal tissues, mainly phosphoglycerides, constitute 0.5–1 per cent of muscle and adipose tissue; the concentration in the liver is usually 2–3 per cent. The most important non-glyceride neutral lipid fraction of animal tissue is made up of cholesterol and its esters, which together make up 0.06–0.09 per cent of muscle and adipose tissue.

Fat

Fats and oils are constituents of both plants and animals and are important sources of stored energy. Both have the same general structure but have different physical and chemical properties. The melting points of the oils are such that at ordinary room temperatures they are liquid and they tend to be more chemically reactive than the more solid fats. The term 'fat' is frequently used in a general sense to include both groups. As well as its major function of supplying energy, stored fat is important as a thermal insulator and, in some warm-blooded animals, as a source of heat for maintaining body temperature. This is especially important in animals that are born hairless, those that hibernate and those that are cold-adapted. Such animals have special deposits of 'brown fat' in which oxidation is uncoupled from adenosine triphosphate (ATP) production and all the energy is liberated as heat.

Fatty acids

Fatty acids are classed into two groups, which are saturated fatty acids and unsaturated fatty acids. The difference between the two is that the saturated group contain no double bonds in their structure, while the unsaturated fatty acids contain at least one double bond in their structure.

The common names are given while names in parentheses represent the modern chemical nomenclature the suffix anoic refers to the saturated fatty acids, and enoic shows that the fatty acid is unsaturated. The suffix monoenoic refers to the presence of one double bond, dienoic, trienoic, tetraenoic four, polyenoic refers to the presence of two, three, four and many double in the fatty acid molecule.

These double bonds are reflected in the formulas for the fatty acids in that they have smaller number of hydrogen atoms relative to the carbon atom present. They possess different physical properties from the saturated ones, they have lower melting points and chemically more reactive or susceptible to oxidation. The term polyunsaturated fatty acids are frequently applied to those having more than one double bond and they have special significance in nutrition.

In many nutrition books linoleic, linolenic and arachidonic acids are classed as essential fatty acids (EFA), because the lack of these fatty acids in the diet of animal especially at young stage (calves, lamb, kids, pigs, and chicks) result to the development of deficiency symptoms. The deficiency symptoms observed in rats include, scaly appearance of the skin, necrosis of the tail, failure of growth, decline in reproduction, lactation, overall production has been observed. So animals need to have the supply of the EFA. In case of chicks, those kept on low fat diets have shown poor growth rates, poor feathering, oedema and high mortality in the 1st few weeks of life.

These EFAs like other polyunsaturated acids they form part of the various membranes and play a part in lipid transport and certain lipoprotein enzymes. In addition they are the source materials for the synthesis of prostaglandins and thromboxanes, hormone-like substance that regulates many cell functions including blood clotting, blood pressure and the immune response. The need for the dietary source of the acid arises from the inability

of animal to introduce double bonds because of the absence of relevant desaturases from animal tissues.

Recent experiments recognise that the most important EFA is **linoleic** and if animals supplied enough quantities of this acid the other two EFA could be synthesised from this acid. The oilseeds are generally rich sources of linoleic acid, linseed is particularly good source of linoleic acid. Considerable quantities of oilseeds in the diet of monogastrics (pigs & poultry) exist, so animals will receive an adequate supply of EFA. In ruminants considerable hydrogenation of unsaturated fatty acids takes place in the rumen thereby reducing the available EFA. Despite this the possibility of ruminants suffering from EFA deficiencies is remote, since they are able to conserve their dietary supply efficiency.

Over supply of polyunsaturated fatty acids may have a nutritional disadvantage, as these unsaturated fatty acids increase the requirement for vitamin E, which appears to serve primarily as an antioxidant, which will result to the shortage of vitamin E and its deficiency condition such as muscular dystrophy & encephalomalacea. This does not occur for hydrogenated oils. Vitamin E functions as a chain breaking antioxidant thereby neutralising free radicals and preventing peroxidation of lipids can destroy the structural integrity of the cells and cause metabolic derangements (disorder).

The double bond which is the reactive site may react with other elements like oxygen or be broken down, and vitamin E prevents this oxidation of double bond which will increase requirement for the vitamin and cause its deficiency symptoms as muscular dystrophy. The position of specific fatty acids to the glycerol is also not completely random, but determined genetically. Example, in specific fats lard (hard pig fat) all of its palmitic acid is found in the 2nd position, while in plant oils all of the saturated acids are

esterified to the 1st and 3rd position. The 2nd position is being esterified by unsaturated fatty acids.

In animals there is a very small opportunity to modify this genetically determined situation by the kind of diet supplied to animals. For example, if pigs are supplied with a diet not containing palmitic acid, there is a possibility to accumulate other fats in their tissue.

3.5. Vitamins

Vitamins are organic compounds that are required in small amounts for normal growth and maintenance of animal life. Unlike the nutrients vitamins are not merely building blocks or energy-yielding compounds but are involved in, or are mediators of, the biochemical pathways. Most food mixes prepared as supplements for ruminants and horses or as the sole food for pigs, poultry, dogs and cats are supplemented with vitamins.

There are at least 15 vitamins which have been classified as essential food factors and their chemical structure and function are known. There are also other chemical compounds similar to vitamins but require further evidence to be classed as new vitamins. These include lipoic acid, coenzyme Q (ubiquinons), vitamin B₁₃, vitamin B_t, vitamin B₁₇, rutin, inositol, and others. These additional compounds have been suspected to have vitamin function or play role as vitamin.

Table. Vitamins important in Animal Nutrition

Vitamins	Chemical name
Fat soluble vitamins	
A	Retinol
D ₂	Ergocalciferol
D ₃	Cholecalciferol
E	Tocopherol
K	Phylloquinone

Water soluble vitamins

B complex

B1	Thiamin
B2	Riboflavin
	Nicotinamide
B6	Pyridoxine
	Panthothenic acid
	Biotin
	Folacin
	Choline
B12	Cyanocobalamin
C	Ascorbic acid

Vitamins play a role in the metabolism process as catalysts. The catalysts play a role in chemical reaction but it does not change its nature in the reaction. They do not involve as a source of energy or as building materials for synthesis of proteins, amino acids, fats, etc. They only serve as catalysts and at the end of the reaction remain unchanged. That is why vitamins are required in minute quantities.

General characteristics

- ✓ Vitamins are of widespread occurrence in nature, both in plant and animal worlds.
- ✓ All common foodstuffs contain more than one vitamin.
- ✓ The plants can synthesize all the vitamins where as only a few vitamins are synthesized in the animals.
- ✓ Some members of the vitamin B-complex are synthesized by microorganisms present in the intestinal tract. Vitamin C is also synthesized in some animals such as rat.
- ✓ Most of vitamins have been artificially synthesized.
- ✓ All the cells of the body store vitamins to some extent.

- ✓ Vitamins are partly destroyed and are partly excreted.
- ✓ Vitamins carry out functions in very low concentrations. Hence, the total daily requirement is very small.

Water-Soluble and Fat-Soluble Vitamins Compared		
	Water-Soluble Vitamins: B Vitamins and Vitamin C	Fat-Soluble Vitamins: Vitamins A, D, E, and K
Absorption	Directly into the blood.	First into the lymph, then the blood.
Transport	Travel freely.	Many require protein carriers.
Storage	Freely circulate in water-filled parts of the body.	Trapped in the cells associated with fat.
Excretion	Kidneys detect and remove excess urine.	Less readily excreted; tend to remain in fat-storage sites.
Toxicity	Possible to reach toxic levels when consumed from supplements.	Likely to reach toxic levels when consumed from supplements.
Requirements	Needed in frequent doses (perhaps 1 to 3 days)	Needed in periodic doses (perhaps weeks or even months)

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Function, Deficiency Signs & Sources of vitamins

Vitamin A (all animals require a source of vitamin A).

Function:

- ✓ Development healthy skin and nerve tissue.
- ✓ Aids in building up resistance to infection.
- ✓ Functions in eyesight and bone formation.
- ✓ It is important in the ration of pregnant females.

Deficiency signs:

- √ Retarded growth in the young, the development of a peculiar condition around the eyes known as **Xerophthalmia**, night blindness and **reproductive disorders**.

Sources:

- √ Whole milk, carotene, animal body oils (cod fish and tuna), legume forages and can be synthetically produced.

Vitamin E

Function:

- √ Normal reproduction.

Deficiency signs:

poor growth,
"crazy chick" disease,
Muscular Dystrophy, "white muscle" disease in ruminants
and swine
"stiff lamb" disease (affects the nerves and muscles).

Sources:

- √ Synthetic for poultry and swine, cereal grains and wheat germ oil, green forages, protein concentrates, oil seeds (peanut and soybean oil).

Vitamin E rapidly destroyed in rancid or spoiled fats. That is why these may cause white muscle disease. Utilization of Vitamin E is dependent on adequate selenium.

Vitamin D

Function:

- √ Is essential for the proper utilization of calcium and phosphorus to produce normal, healthy bones.

Deficiency signs:

- √ Retarded growth, misshapen bones (rickets), lameness and osteoporosis.

Sources:

Whole milk, sun-cured hays, forage crops, fish liver oils, irradiated yeast.

Vitamin K**Function:**

- √ Necessary for the maintenance of normal blood coagulation.

Deficiency signs:

- √ Blood loses its power to clot or the time needed for clotting is longer and serious haemorrhages can result from slight wounds or bruises.

Sources:

- √ Green leafy forages, fish meal, liver, soybeans, rumen and intestinal synthesis, and the synthetic compounds.

3.6. Minerals

These are inorganic nutrients necessary in serving the animal body in many different ways. Minerals have many roles in addition to their catalytic role by activation of many enzymes. Other roles of minerals include:

- ❖ They are building blocks of animal tissues such as constituents of bones and teeth (structural role), and also essential for synthesis of structural proteins like the mineral sulphur.
- ❖ Minerals are components of organic compounds like iron haemoglobin, cobalt is vitamin B₁₂.
- ❖ Minerals serve a variety of functions as soluble salts in blood and other body fluids playing role in maintenance of osmotic relations and acid base equilibrium (electrochemical function).

The mineral elements in feed or animal tissue as a group could be determined by burning off the organic matter at high temperature in furnace (500-600°C for 8 hours) and weighing the residue, which is called ash. Such a determination tells nothing about the specific elements present, and ash

may include carbon from organic matter as carbonate when base forming minerals are in excess. The determination of the individual minerals could be accomplished by an instrument called atomic absorption spectrophotometer. The determination of individual minerals has a limitation since not tell us the form the mineral is found which affects the availability of the minerals for the animals.

For example, calcium found in free form is more available but be precipitated by oxalates. Therefore, calcium-oxalate is less available form. Phosphorous found as phytic acid or phytate also less available than other forms like calcium phosphate. So the form should be known. Minerals are essential for the functions mentioned. In the body we find many minerals, some of which are essential, but others not yet considered essential. Some of the minerals may be there in the body simply because they were present in the ingested food. To determine for a mineral is essential or not we undertake purified diet experiments. An essential mineral element is restricted to minerals which have been proved to have a metabolic role in the body. When an animal supplied with purified diets lacking the mineral we want to test if;

- ❖ Deficiency symptoms appear and
- ❖ Those symptoms can be eradicated or prevented by adding that particular mineral or element to the experimental diet, the minerals is said to be essential.

But when we follow such procedure in determining essential mineral elements we have to provide purified diets which are practically not easy as minerals required for normal health and growth by animals is in minute quantities and construction of diets deficient in the mineral in question is often difficult to achieve.

In such studies it is also necessary to monitor the environment not only water and feed supplied. The environment should be free from contamination as the animals may obtain the minerals from cages, troughs,

attendants or dust in the atmosphere which increase the difficulty of determining essential elements. In recent years, improved technology such as ultraclean, more or less, trace-element-sterile isolators and highly purified amino acid diets have resulted in the demonstration of the dietary essentiality of several minerals such as silicon and vanadium. Furthermore, more precise ways and accurate methods of determining minute quantities of trace elements has been developed. Accurate analysis is essential, as minerals are mostly found and required in minor quantities.

Classification of essential mineral elements

Essential minerals are classified into two depending upon their concentration in the animal or up on the quantity animals require these elements.

1. Major element: are elements required in relatively larger quantities
2. Minor elements (trace elements) - are elements required is relatively less quantities.

Normally trace elements are present in the animal body in a concentration not greater than 50mg/kg and are required less than 100 mg/kg diet while the concentration of major elements in the animal body is greater than 50mg/kg. Normally trace and major elements are expressed in different units (values) whereby, major elements are expressed in percentage (%) of the feed or g/kg as it larger quantity whereas minor elements are expressed in PPM (parts per million), or mg/kg, or g/kg.

Nutritionally important essential mineral elements and their approximate concentration in the animal body are indicated in the table shown. In addition to the elements shown in the table chromium (Cr), fluorine (F1), silicon (Si), Vanadium (V), tin (Sn), arsenic (As) and nickel (Ni) have been added to the list of dietary essential minerals. It has been suggested that as many as 40 or more elements may have metabolic roles in mammalian tissues. Fortunately, any of this trace elements, especially those of more recent discovery are required in such minute quantities or are so widely

distributed in animal feeds, their deficiencies are likely to be extremely rare under normal practical condition.

Nutritionally important essential mineral elements and their approximate concentration in the animal.

Major Element	g/kg	Minor Element	mg/kg
Ca	15	Iron (Fe)	20-80
P	10	Zink(Zn)	10-50
K	2	Copper (Cu)	1-5
Na	1.6	Molybdenum (Mo)	1-4
Cl	1.1	Selenium (Se)	1-2
S	1.5	Iodine (I)	0.3-0.6
Mg	0.4	Manganese (Mn)	0.2-0.5
		Cobalt (Co)	0.02-0.1

Calcium (Ca)

Function:

- ✓ Major component of bones and teeth and essential in blood coagulation, nerve and muscle function and milk and egg production.

Deficiency signs:

- ✓ Retarded growth, deformed bones in young animals (rickets), and soft shelled eggs and osteoporosis in older animals.

Sources:

- ✓ Milk, oyster shells and limestone.

Sodium chloride

Considered together because of a close biochemical relationship and are provided as common salt (NaCl)

Function:

- ✓ Required for the formation and retention, concentration and pH of body fluids, such as protoplasm, blood.
- ✓ Important in the formation of digestive juices and functions in nerve and muscle activity.

Deficiency signs:

- ✓ Poor condition and depressed appetite. Most farm produced feeds are deficient in these two minerals.

Sources:

- ✓ Salt supplements and injectable products.

Phosphorus (P)

Function:

- ✓ Essential for the formation of bones, teeth, and body fluids.
- ✓ Required for metabolism, cell respiration and normal reproduction.

Deficiency signs:

- ✓ Similar to calcium deficiency, lack of appetite, poor reproduction and unthrifty appearance.

Sources:

- ✓ Dicalcium phosphate, bone meal, and low fluorine phosphates.

Potassium (K)

Function:

- ✓ Retention and formation of body fluids, pH concentration of body fluid and rumen digestion.

Deficiency signs:

- ✓ Nonspecific and unlikely under most conditions but may have decreased feed consumption and efficiency.

Sources:

- ✓ Roughages.
- ✓ Grains are less than roughages.

Manganese (Mn)

Function:

- ✓ Fetal development, udder development, milk production and skeleton development.

Deficiency signs:

- ✓ Abortions, reduced fertility, deformed young and poor growth.

Sources: Most use trace mineralized salt.

Micro minerals**Copper (Cu)****Function:**

- ✓ Should be present in animal tissues for iron to be properly utilized, hemoglobin formation and synthesis of keratin for hair and wool growth.

Deficiency signs:

- ✓ Poor pigmentation of feathers, stringy wool, sway back lambs, lack of muscle coordination and anemia.
- ✓ De-pigmentation classically occurs as grey/brown discoloration of the coat especially around the ear margins and eyes.

Sources:

- ✓ Forages and copper salts.

Iron (Fe):**Function:**

- ✓ Essential for the function of every organ and tissue of the body (Hemoglobin).

Deficiency signs:

- ✓ Seldom occurs in older animals, nutritional anemia, labored breathing and pale eyelids, ears and nose.

Sources:

- ✓ Forages and copper or trace mineral salts.

Cobalt (Co)

Function:

- ✓ Required as a nutrient for the microorganisms in ruminants and thereby aids in rumen synthesis of Vitamin B₁₂.
- ✓ Because swine cannot manufacture B₁₂ from cobalt, the diets are supplemental with vitamin B₁₂ instead.

Deficiency signs:

- ✓ Lack of appetite, loss of weight, rough hair coat, anemia, decreased milk and wool production and death in extreme cases.

Sources:

- ✓ Legume forages and salt containing cobalt.

Magnesium (Mg)

Function:

- ✓ Similar to calcium and phosphorus.

Deficiency signs:

- ✓ Animals are irritable, their heart beat is irregular and there is severe kidney damage.

Sources:

- ✓ Mineral supplements and ordinary feeds.

Although we have been considering the essential role of minerals in animal nutrition, it is important to realize that many are toxic – causing illness or death – if given to the animal in excessive quantities. This is particularly true of copper, selenium, molybdenum, fluorine, vanadium and arsenic. Copper is a cumulative poison, the animal body being unable to excrete it efficiently; small amounts of copper given in excess of the animal's daily needs will, in time, produce toxic symptoms.

This also applies to the element fluorine. Supplementation of any diet with minerals should always be carried out with great care, and the indiscriminate use of trace elements in particular must be avoided. Ideally, the supplement should be tailored to the target animal and a blanket oversupply should be avoided as it is wasteful and potentially dangerous. Minerals should be added to concentrate foods via a premix and thoroughly mixed to avoid 'hot spots' of high concentration and potential toxicity.

4. Digestion, Absorption and Metabolism of Nutrients of Farm Animals

Many of the organic components of food are in the form of large insoluble molecules, which have to be broken down into simpler compounds before they can pass through the mucous membrane of the alimentary canal into the blood and lymph. The breaking down process is termed 'digestion', and the passage of the digested nutrients through the mucous membrane 'absorption'. The processes important in digestion may be grouped into mechanical, chemical and microbial activities. The mechanical activities are mastication and the muscular contractions of the alimentary canal. The main chemical action is brought about by enzymes secreted by the animal in the various digestive juices, though it is possible that plant enzymes present in unprocessed foods may in some instances play a minor role in food digestion. Microbial digestion of food, also enzymic, is brought about by the action of bacteria, protozoa and fungi, microorganisms that are of special significance in ruminant digestion. In monogastric animals, microbial activity occurs mainly in the large intestine, although there is a low level of activity in the crop of birds and the stomach and small intestine of pigs.

Digestion is a process whereby large insoluble feed particles are broken to simple, soluble and absorbable particles.

Absorption on the other hand is the passage of the digested nutrients through the mucous membrane into blood circulation or lymph.

Metabolism is a general term given to the sequence of chemical processes that take place in the living organism. These reactions continue as far as the living body exists

4.1. Digestion in monogastric mammals.

The term “monogastric” refers to the structure of the stomach. In a monogastric digestive system, the stomach has a simple structure consisting of a single compartment.

A number of species have a monogastric digestive system, including swine, horses, dogs, rabbits, and fowl. All of the mammals listed here have similar systems, although some minor differences do exist between them. Fowl, however, have a digestive system that differs from the others, including organs not found in the other species.

The digestive tract can be considered as a tube extending from mouth to anus, lined with mucous membrane, whose function is the prehension, ingestion, digestion and absorption of food, and the elimination of solid waste material. The various parts are mouth, pharynx, oesophagus, stomach, and small and large intestine. The movement of the intestinal contents along the tract is produced by peristaltic waves, which are contractions of the circular muscle of the intestinal wall. The contractions are involuntary and are under overall autonomic nervous control.

Digestion begins when feed enters the mouth. The feed is then carried through a tube called the esophagus to the stomach. When leaving the stomach, the feed moves into the first section of the small intestine, which is called the duodenum. After traveling through the rest of the small intestine, what remains of the feed is first emptied into the part of the large intestine named the cecum and then into the colon. Finally, the waste products are

passed into the lower end of the large intestine, which is referred to as the rectum, and out of the body through the anus.

While they are not a part of the digestive system, the pancreas, gall bladder, and liver also play a role in digestion. They release substances that aid the digestive system in performing its function. However the horse, unlike the other animals, does not have a gall bladder.

The path followed by feed in fowl differs somewhat due to the different parts of its digestive system (Figure 1.2). Feed enters the system through the beak and passes through the esophagus, which is called the gullet, to an organ referred to as the crop. From the crop it passes into the glandular stomach, or proventriculus, and then the gizzard, or ventriculus, before entering the small intestine. At the point where the small intestine and large intestine join are two ceca. After passing the ceca, the undigested material moves through the large intestine to the cloaca and exits the body through the vent.

4.1.1. Digestion in the fowl

The gut of poultry differs from other monogastric animals in many aspects.

1. In the fowl the lips and teeth are absent and replaced by another structure called beak. Taste in poultry is limited.
2. If we see structure of gut of poultry we have beak and then esophagus. Esophagus in birds is modified to form a pear-shaped sac called crop. The main function of crop is as a reservoir for holding food and plays little role in the digestion process. Some microbial activity occurs there and results in the production of lactic and acetic acids. Action of salivary amylase also occurs here.
3. The esophagus terminates at the proventriculus of glandular stomach, or end of esophagus has proventriculus or glandular stomach. This is also called true stomach, because there are certain glands that produce gastric juice, similar to the structure and function of pig's stomach. This contains pepsinogen & HCl.

The need for crop becomes obvious when you see the size of proventriculus which is small in capacity. Therefore, crop serves as an additional store so that the feed will be stored temporary until transferred to proventriculus and only small quantity of food is gradually brought to proventriculus. The proventriculus has minimum inherent motility and food passes through as a result of esophageal contraction.

4. The glandular stomach leads to the gizzard which has no counterpart in the pig. This is a modification of gut of poultry, made up of very strong muscles which are in constant motion thereby facilitating physical breakdown of feeds. The gizzard wall produces koilin, a protein-polysaccharide complex similar in its amino acid composition to keratin, which hardens in the presence of HCl. Gizzard is a muscular organ which undergoes rhythmic contraction and grinds the food with moisture into a smooth paste.

Poultry has another assisting mechanism for physical degradation. These are small stones in the gizzard called grit, which facilitate physical degradation of feed by about 10%. This structure or grit could be assumed as substitute of teeth found in other farm animals.

After feed materials get mixed with gastric juice in the proventriculus the feed goes to the gizzard and chemical degradation is limited in the proventriculus because of hard nature of the feed. In the gizzard there will be physical degradation which increase the surface areas of the feed to be attacked by enzymes of proventriculus, but **gizzard** not produce enzymes. Therefore, proventriculus & gizzard are equivalent in function to the mammalian stomach. From the gizzard the feed goes to small intestine which is similar to other farm animals. In fowl two bile ducts and three pancreatic ducts pour to small intestine. From small intestine feed goes to large intestine which you find two large blind sacs (ear like structure) called caeca at the junction of small intestine and large intestine. The caeca

functions mainly as absorption organs, but not essential to the fowl as surgical removal causes no harmful effects. It does not play significant role in fermentation to poultry.

The whole structure of large intestine is much shorter in poultry and found very short colon in fowl whose function is to transport digesta to cloaca. The large intestine terminates in the cloaca, a special structure not equivalent to the anus since functions as an orifice where digestive, urinary and reproductive system products are removed under this common opening. We have elimination of feces (grayish or black portion) and urine (white portion) together. Urine is mostly uric acid. Egg is also removed by this same office.

The enzymes present in gut of fowl are similar to other mammals, although lactase has not been detected. You find salivary α -amylase whose action in the stomach continues in the crop. Pancreatic juice contains same enzymes as the mammalian secretions. Digestion of carbohydrate, proteins and fats in the small intestine believed to be similar to pig. Intestinal mucosa also produces similar enzymes like mammals.

Absorption of digested nutrients

The main organ for the absorption of dietary nutrients by the monogastric mammal is the small intestine. This part of the tract is specially adapted for absorption because its inner surface area is increased by folding and the presence of villi. Although the duodenum has villi, this is primarily a mixing and neutralising site, and the jejunum is the major absorptive site. Absorption of a nutrient from the lumen of the intestine can take place by passive transport, involving simple diffusion, provided there is a high concentration of the nutrient outside the cell and a low concentration inside.

The vascular system in the villi is arranged so that the concentration gradient is maximised. Nutrients such as monosaccharides, amino acids and small peptides are absorbed at a faster rate than can be accounted for by passive diffusion. The absorption of such molecules is aided by specific carrier transport systems in which carrier proteins reversibly bind to and transfer the nutrient across the brush border and basolateral membranes of the epithelial cells. The transfer may be by facilitative transport, in which the carrier transports the molecule down its concentration gradient. Alternatively, absorption may be by a process of active transport (or co-transport). Here, the carrier has two specific binding sites and the organic nutrient is attached to one of these while the other site picks up a sodium ion (in the case of monosaccharides and amino acids) or a hydrogen ion (in the case of dipeptides). The sodium or hydrogen ion travels down the chemical gradient and the loaded carrier thus moves across the intestinal membrane and deposits the organic nutrient and the sodium or hydrogen inside the cell. The empty carrier then returns across the membrane, free to pick up more nutrients.

A third method of absorption is by pinocytosis 'cell drinking', in which cells have the capacity to engulf large molecules in solution or suspension. Such a process is particularly important in many newborn suckled mammals in which immunoglobulins present in colostrum are absorbed intact.

4.2. Digestion in ruminants

In contrast to an animal with a monogastric digestive system, a ruminant has four stomach compartments and can utilize some feeds more efficiently than a monogastric animal. Ruminants are important to the animal industry because they can use hay and pasture productively.

In the GIT of the ruminant, ingested food is exposed to very extensive pregastric fermentation. Most of the ingesta is fermented by microbes before it is exposed to typical gastric and intestinal digestive chemicals and

enzymes; thus, this is quite a different system than for typical monogastric animals.

The reticulo-rumen provides a very favorable environment for microbial activity and survival. It is moist and warm and there is an irregular introduction of new digesta and a more or less continual removal of fermented digesta and end products of digestion. A wide variety of bacterial types may be found in the rumen and some 35+ species of ciliate protozoa have been identified from the rumen of animals in different situations, although the variety that may be found in any one animal is considerably less. Protozoa numbers vary widely, but typical counts are on the order of 20,000 to 500, 000/ml. They are much larger than bacteria and numbers are less, but they represent about the same amount of microbial protoplasm as from the bacteria. In addition to bacteria, protozoa, fungi and yeast are also found in the rumen. The fate of rumen micro-organisms is that they pass into the abomasum and intestine and are then digested by the host animal.

The net effect of this thriving microbial population is that it has a marked effect on nutrient requirements and metabolism of the host animal. Fibrous feeds are digested more efficiently in the rumen than in the large intestine or cecum. Cellulose and hemi-cellulose can be digested by microbes. Bacteria can utilize simple forms of nitrogen such as urea, to synthesize their cellular proteins. This reduces the dependence of the animal on high quality dietary proteins and allows the use of compounds such as urea as protein replacement in their diets. A further benefit is that rumen synthesis is extensive for all vitamins except vitamin A, D, and E and as a result, the animal is not dependent upon a dietary source of these vitamins.

One of the chief disadvantages of rumen fermentation is that most dietary proteins are partially degraded and the ammonia which is produced is re-synthesized into microbial proteins. This is a wasteful process. In addition, readily available carbohydrates such as sugars and starches are rapidly and

completely degraded, the major end products are the volatile fatty acids, namely acetic, propionic and butyric acid. Smaller quantities are produced of the branched chain fatty acids like valeric, iso-valeric and iso-butyric, these come from the breakdown of amino acids resulting from the microbial metabolism of proteins. These VFAs are used readily by the animal's tissues and are used less efficiently for energy than the original carbohydrates. In the fermentation process as much as 8-10% of the energy consumed is converted to methane (CH_4), as gas which is wasted and animal can not utilize. The feed conversion efficiency is low in ruminants than monogastric animals. The feed conversion ratio (FCR) in ruminants is twice or more that of monogastric species and the FCR is defined as the units of feed consumed per unit of product produced.

The overall effect of rumen fermentation is that these animals can survive and do well on less complex and lower quality diets than monogastric species but on the other hand good quality dietary ingredients are used less efficiently than by monogastric.

About 150 liters of saliva is produced per day in mature cow. Saliva contains large amounts of sodium bicarbonate which is vital in maintaining an appropriate pH in the rumen by buffering the acids produced. Saliva is also important in maintaining optimum moisture content.

In the young ruminants the reticulum, rumen and omasum are relatively under developed at birth because the suckling animal depends on abomasum and intestine for digestive functions. As soon as the animal starts to consume solid food, the other compartments develop rapidly and they attain relative mature proportions by about 8 weeks in lambs and kids, 3-4 months in deer and 6-9 months in domestic bovines. An anatomical peculiarity of ruminant species is that they have a structure called the esophageal or reticular groove. This structure begins at the lower end of the esophagus into the omasum. Its function is to allow milk consumed by the

suckling animal to bypass the rumen and, thus, escape bacterial fermentation. The groove does not appear to remain functional in older animals unless they continue to suckle liquid diets. In the ruminant stomach there is a well developed pattern of rhythmic contractions of the various stomach compartments which act to circulate ingesta into and throughout the rumen, into and through the omasum and on the abomasum. The contractions aid in regurgitation during rumination. This is a phenomenon peculiar to ruminants. It is a controlled form of vomiting, allowing semi liquid material to be regurgitated up the esophagus, swallowing of the liquid and a deliberate remastication of the reswallowing of the solids. Ruminants may spend 8 hours/ day or more in rumination, the amount of time depending upon the nature of their diet. Fibrous diets result in more rumination time.

Eructation (belching of gas): Microbial fermentation in the rumen results in the production of large amounts of gases (CO_2 and CH_4) which must be eliminated. This is accomplished by contractions of the upper sacs of the rumen which forces the gas forward and down; the esophagus then dilates and allows the gas to escape. During the process much of the gas penetrates into the trachea and lungs, after which it is exhaled through the nostrils.

The digestive processes can be classified as mechanical, biochemical and microbial. Much of the mechanical breakdown takes place in the mouth but all the other sections of the gut are very muscular and help to move the feed along by peristaltic action and also mix and churn the ingesta. The biochemical digestion is carried out largely with the help of enzymes secreted into the gut at various stages. The microbial digestion or fermentation process takes place mainly in the rumen but also to a lesser extent in the hind gut.

The ruminant's stomach consists of four compartments; rumen (paunch), reticulum (honeycomb), omasum and abomasum (true stomach). In young calf or unweaned calf the abomasum acts as true stomach. As the

ruminant is weaned, by changing from the liquid diet on a solid diet, the other three chambers of the compound stomach enlarge considerably, so that in the adult animal the abomasum occupies a small volume. In the adult, the rumen or reticulo-rumen when completely full of feed the volume of this chamber can occupy half or more of the total volume of the abdominal cavity. Abomasum secretes large amounts of gastric juices of very low pH (high acidity) and this effectively kills off any rumen microbes which enter this organ in a live state. The gastric juices commence protein digestion which is carried out by the action of enzymes, for instance pepsin, which break down the large protein molecules into smaller peptides.

The reticulo-rumen only functions in the weaned calf or lamb. Weaning is change from liquid to solid feeding. The reticulo-rumen forms a large fermentation organ which contains billions of microbes, of which the two main types are bacteria and protozoa. The microbial population ferments the organic matter contained in the solid feed, converting it into very simple chemical substances, such as ammonia and volatile fatty acids. The fermentation takes place in the anaerobic environment meaning in presence of carbon dioxide (CO₂). Some of these simple chemicals are absorbed through the reticulo-rumen wall into the blood stream whilst others are absorbed into the bodies of the micro-organisms to form the so-called 'microbial mass' or biomass. The two most important nutritional functions of the reticulo-rumen are the modification of the energy and protein fractions of the feed into very simple chemicals entities. Some of these simple molecules are digested by passing through the reticulo-rumen wall into the blood; others are used as a feed substrate by the microbes which proceed to build them up again into complex molecules, especially microbial protein. The reticulo-rumen acts as a fermentation vat which functions on a continuous production principle and thus requires a constant supply of feed material to keep it going. Instead of two or three times feedings it is better to split the

feeding in several times so that the reticulo-rumen is being frequently replenished with new feed materials.

The reticulo-rumen is a very muscular organ undergoing frequent movements for adequate mixing of the mass of fermenting material so as to bring the suspension of microbes in contact with the organic matter in the feed. Inside of the rumen contains many folds like projections. The lining of the reticulum is more symmetrical and forms a trellis-like pattern or honeycomb, hence its name. The mass of papillae present in the rumen which increases the surface area in contact with the ingesta. In the rumen fats and oils present in the feed are modified in their chemical composition. The most unsaturated fats entering the reticulo-rumen are hydrogenated into saturated fat before they pass into omasum. Some will be used by the microbial organisms to form microbial fats in their bodies. A few protected unsaturated fats will escape hydrogenation and pass through unchanged. The rate of flow of the digesta from the reticulo-rumen into the omasum varies accordingly to the type of diet fed. Typical figures are 4 lit/hour for adult cows and 0.5 lit/hour for adult sheep.

Conditions in the Rumen

The conditions in the rumen are not only complex but they are intermittent. The rate at which feed enters the rumen will be very different during grazing or meal feeding. Salivary flow rate is not steady and rumination activity that is not continuous will depend on the type of diet. The flow of substances into and out of the rumen may involve more than one pathway. Volatile fatty acids can leave the rumen via passage into the lower tract or they can be absorbed and partly metabolized in the epithelium. Urea may enter the rumen via saliva or directly from blood through the rumen epithelium. Despite all these variations there are certain generalizations that we can make regarding the rumen:

1. Temperature is usually maintained within the range of 38-41°C with 39°C used as a

common mean temperature.

2. Rumen pH can range from around 7.0 on forage diets to as low as 4.6 on high-grain

diets.

3. Mean redox potential is -350 mv reflecting the strong reducing environment and the

absence of oxygen.

4. Carbon dioxide and methane are the major gases present in the rumen.

5. The solid and liquid digesta leave the rumen at different rates.

Acetate is found in the greatest concentration in the rumen followed by propionate and butyrate. Short chain fatty acids are passively absorbed through the rumen wall and the rate of absorption is dependent upon chain length, pH and concentration. At pH 6.5 or below longer chain fatty acids are absorbed at a higher rate, but at pH above 6.5 rates are similar. In general, undissociated acids are more rapidly absorbed, therefore as pH decreases absorption increases. Low pH also favors the absorption and production of lactic acid. In cases when large amounts of grain are fed lactic acid can accumulate and become toxic to the animal. Ammonia is readily absorbed and the rate of absorption is dependent on concentration and pH. It is rapidly absorbed at a higher pH and decreases as pH drops.

Omasum: The word omasum means a book, and the organ is so named because the inside surface is formed by a large number of layers of epithelial tissue giving the appearance of the leaves of a book. The feed passes into

the omasum only when it has been ground down or fermented into fine particles of the same consistency as finely chopped mint in a well-made mint sauce. The feed particles together with considerable quantities of rumen fluid, much of it derived from saliva, enter the omasum in a ratio of about 10 parts fluid to 1 part water. The main function of omasum is to absorb water from the digesta, so that the material can enter the abomasums and mid-gut in a more concentrated state. Very less fermentation occurs in the omasum because the material is too dry to enable the microbes to function efficiently. The rumen flora requires a very watery medium in which to thrive and multiply. There is some evidence that absorption of VFA's and electrolytes takes place in the omasum, but the chief site of VFA's absorption is through the rumen wall.

Small intestine: The surface area of small intestine is proportionally greater than its length because the internal surface contains many villi, small rod-like projections which increase the surface area many times. The villi ensure that the maximum amount of digesta is in contact with a large area of absorptive tissue. The epithelial or absorptive cells lining the villi are renewed every few days. The debris from these dead cells provides some of the endogenous loss of energy and protein from the animal. The small intestine is a main site of absorption of the protein fraction of feed. Proteins in the form of amino acids derived from dead micro-organisms (microbial protein) or from underaded protein contained in the feed as ingested, pass through the wall of the small intestine and into the small capillaries which cover its external surface. A chyme (feed converted by gastric secretion into an acid pulp) is acted on by bile and pancreatic juice and afterwards converted to chyme, a milky fluid, in the small intestine.

The passage of the digesta through the small intestine consists of two steps forward and one step backwards and this peristaltic action having the general effect of moving the digesta forward. The small intestine enters the side of the colon leaving a blind end, the caecum on one side.

Colon (Large intestine): is also called large intestine. The main function of colon is to remove excess water from the digesta. Colon is inhabited by numerous micro-organisms and some secondary fermentation takes place throughout its length. There may indeed be further fermentation of residual fibrous materials and further absorption of VFA's from the colon into the blood stream.

Caecum: the caecum is a short cul de sac leading from the alimentary canal where the small intestine joins the colon. Its function is to act as a secondary fermentation chamber, continuing the process of fiber digestion which primarily takes place in the reticulo-rumen. The movement of the digesta in the caecum must take place in both directions, and there is a complex cycle of caecal muscular movements which enable the organ to be emptied and filled at regular intervals. The microbes in the organ may also break down any residual protein entering this organ, producing ammonia as the end-product. Some absorption of this ammonia into the blood capillaries takes place, but the amount of nitrogen absorption is small compared to that which takes place in the reticulo-rumen.

Microbial population in the Rumen

Bacteria = 10^{10} / ml of rumen liquor

Cellulolytic bacteria = 10^7 / ml of rumen liquor

Protozoa = 10^5 / ml of rumen liquor

Fungus = 10^3 / ml of rumen liquor

Yeast = very small numbers

Digestion in young unweaned ruminant

In the young ruminants the reticulo-rumen is undeveloped, and the main functional chamber is the abomasum. At this stage the young lamb or calf has a digestive system more like a pig than a ruminant. They are also known as monogastric or pre-ruminants. In unweaned animal when milk is consumed a complicated bypass arrangement comes into operation. This enables the milk to pass down the oesophagus and hence through a temporary tube-like structure, known as the oesophagus groove, caused by a folding of the lining of the wall of the reticulo-rumen, and then straight through to the abomasum. When the young ruminant eats small quantities of solid feed the oesophageal groove does not close, so that the material enters the rumen. The solid feeds like straws, hay and other fibrous feed stimulate the development of reticulo-rumen. They also stimulate the muscular movements which is essential part of the fermentation process. The VFA's produced by the fermentation of solid material also assist the reticulo-rumen to develop its full function. One of the major enzyme secreted by the abomasum in the young calf and lamb is rennin, which coagulates the milk protein (casein) forming a solid clot (curd). This clot remains in abomasum for some hours and then broken down by the action of rennin and pepsin. When young ruminants placed on early weaning system it is important that they are not moves on to a solid diet provided:

- 1) The calf must be consuming a solid feed in order to prevent a post-weaning check and feed required at this stage is 1 kg/day.
- 2) The animal must be ruminating or chew the cud. Until rumination has started calves are unable to digest solid food properly because the fermentation activity of the reticulo-rumen has not moved into top gear.

The colostrum or fore-milk is richer in milk solids, especially protein and contains a number of immunoglobulin which reduces the risk of infection of

the calf or lamb in the first few days of life. Therefore, it becomes important to suckle the colostrum from the dam.

Organs associated with ruminant digestion:

Salivary glands: are situated in the head and they secrete copious quantities of saliva into the mouth and gut, up to 150 lit/day. Saliva provides water to enable the feed to be masticated into a sort of paste before being swallowed. The saliva acts as the buffering agent when enter the reticulo-rumen. Saliva is beneficial for production of VFA's in the rumen.

Liver: the liver stores energy in the form of glycogen, liver extracts ammonia from the blood stream and converts it into urea and it converts numerous complicated chemicals from one form to another, to enable them to be utilized with greater efficiency at the appropriate anatomical site. The liver produces the bile which helps in the digestion of fat by promoting emulsification.

Pancreas: the function of pancreas is to secrete numerous enzymes into the duodenum which continue the process of protein and carbohydrates digestion and commence the process of digestion of fats. The pancreas produces the insulin which is secreted into the blood and plays a vital role in intermediate carbohydrates metabolism in the body tissues. One of its functions is to assist in the conversion of blood glucose to glycogen which is stored in liver as energy reserve.

Kidneys: the function of kidneys is to excrete waste products from the blood and to discharge in the form of urine to the bladder. Three types of waste products are excreted by the kidneys, namely 1) waste products of nitrogen metabolism (uric acid & others) 2) wastes of energy metabolism such as ketone bodies. 3) and unwanted minerals such as excess of Sodium.

Digestion of carbohydrates in the reticulo-rumen (Fermentation of carbohydrates)

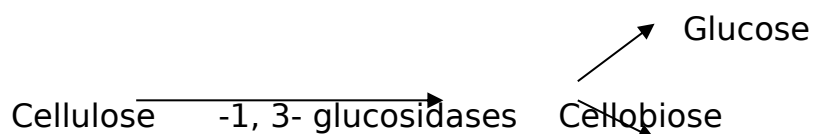
Carbohydrate degradation in the reticulo-rumen of farm animal production is very important phenomena, thereby grazing animals or ruminants depend upon grazing vegetation which is almost carbohydrates with less proportion of fats, proteins and minerals. Thus the degradation of carbohydrates is very important aspect of utilisation of feeds of ruminants.

The diet of ruminants contain considerable quantities of cellulose, hemicellulose, starch & water soluble carbohydrates mostly in the form of fructans, pentosans, xylans, and also find lignin in association to these carbohydrates. Young pasture frequently sole feed for ruminants; contain about 40% cellulose and hemicellulose, and 20% water soluble carbohydrates. In mature herbages (hays and straw) the proportion of cellulose and hemicellulose is much higher (60%) and water soluble carbohydrates content decrease. So depending on age of the plants, the composition of carbohydrate will differ.

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

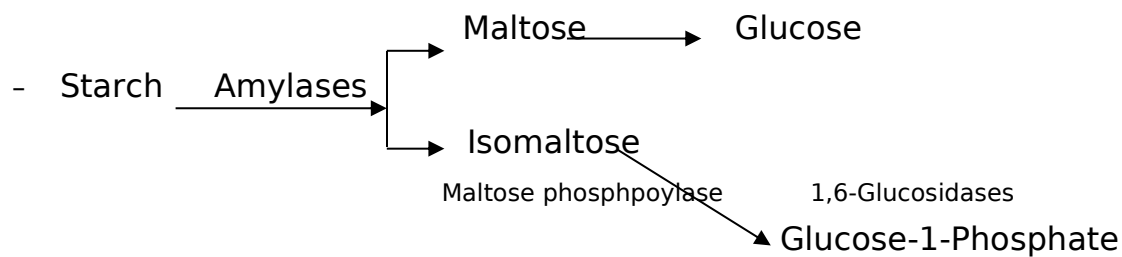
1. Digestion of complex carbohydrates into simple sugars which is accomplished by extracellular microbial enzymes or enzymes produced by microbes found in the reticulo rumen action of which is outside the microbes that produce them.

Cellulose is one major carbohydrate consumed by ruminants which could be decomposed by one or more α -1,3- glucosidases to cellobiose which is then converted either to glucose, or through the action of phosphorylase to glucose -1- phosphate.

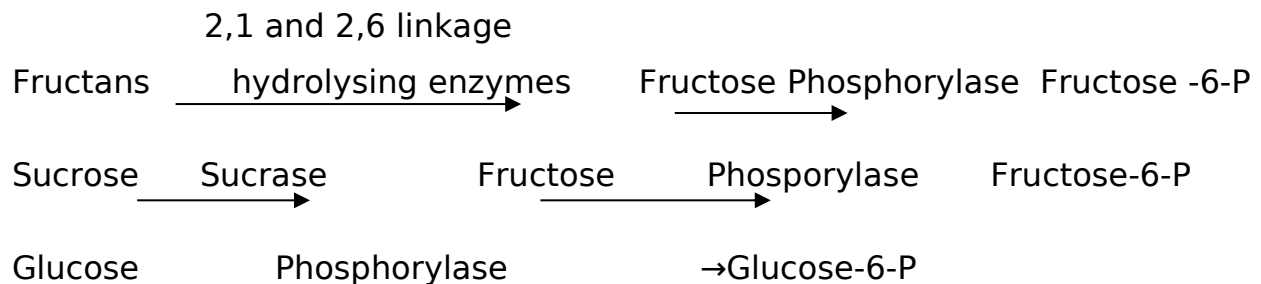


Phosphorylase Glucose -1- phosphate

Starch and dextrins are 1st converted by amylases to maltose and isomaltose and then by maltases, maltose phosphorylases or 1,6-glucosidases to glucose or glucose-1-phosphate.



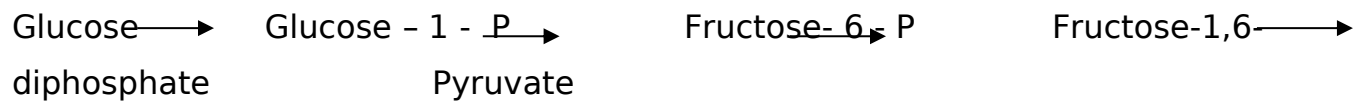
Fructans are hydrolysed by enzymes attacking 2, 1 and 2,6 linkage to give fructose, which may also be produced together with glucose by the digestion of sucrose.



Pentoses are the major product of hemicellulose breakdown which is brought by enzymes attacking -1,4 linkage to give xylose and uronic acid. The latter are then converted to xylose. Xylose may also be produced from hydrolysis of xylans which may form a significant part of the dry matter of grasses.

2. The 2nd stage in rumen degradation is that the simple sugars produced in the 1st stage of carbohydrate digestion in the rumen are rarely detectable in the rumen liquor as they are immediately taken up and metabolised by intracellular enzymes of micro-organisms intra-cellularly. For this second

stage, the pathway involved is similar in many respects to those followed in the metabolism of carbohydrates by the animal itself.



Pyruvate forms intermediate product. Pyruvate production is the 1st stage both under anaerobic or aerobic condition from glucose. This releases some energy for the microbes and produces four atoms of hydrogen. Pyruvate under aerobic condition oxidise to CO₂ and H₂O with further production of energy. One kg of glucose in this way gives 16 MJ of energy but only 1/6 as much under anaerobic as there is incomplete oxidation.

Under anaerobic environment of the rumen the pyruvate is oxidised in a variety of ways to result different volatile fatty acids (VFA) is cell of micro-organisms. The main acids produced in the rumen are acetic, propionic and butyric acids, and gasses CO₂ and CH₄ (methane). These are main end products of metabolism of carbohydrates in the rumen.

Additional smaller quantities of VFA (branched type can be produced in the rumen from deamination of amino acids. Isobutyric is derived from valine, 2-methyl butyric from isoleucine, valeric from proline, 3-methylbutyric from leucine. In terms of quantity the 3 VFA acetate, propionate and butyrate are the most important, and also gases CO₂ and CH₄. The total concentration of VFA in the rumen liquor varies between 2 and 5 g/liter depending on the kind of the animal diet, and the time sample taken or time elapsed since the previous meal.

The relative proportion of the different VFA also varies with feed type. The predominant acid is acetic, and roughage diets high in cellulose give rise to acid mixtures particularly high in acetic acid. As the proportion of concentrates in the diet increase, the proportion of acetic acid fall and

propionic acid proportion rise. With all concentrate diet propionic acid may even be more than acetic acid because of the decrease in the number of cellulolytic bacteria which are favoured by high cellulose diets, but promote starch fermenting bacteria which promote propionate production which is needed in fattening animals.

When these VFAs produced for acetate and butyrate a lot of hydrogen is produced. But to keep the hydrogen level at constant, there is a mechanism where the excess hydrogen reacts in methanogenic bacteria with CO₂ and converted it to methane.



The quantity of methane produced is quite large about 7% of its food energy. So an effect directed to decrease the production of CH₄ formation may economise energy loss. Some CH₄ may also be derived from formate by the process of methanogenesis (HCOOH + 6H⁺ → CH₄ + 2H₂O). Of all the gasses produced in the rumen methane account for 30 to 40%, CO₂ account for 40%, hydrogen for 5%, and the oxygen and nitrogen variable based on the content in the ingested air. Most of gases are removed by eructation. If the gas accumulates it causes bloat.

If there is a possibility of decreasing hydrogen production, we can economise the energy. This could be accomplished by decreasing the reaction that produces most of the hydrogen, acetic acid formation. For these different chemicals are produced to be used as feed additive, example, rumensin also called momensin. Small quantity of momensin decrease hydrogen formation and methane production too by changing the molar proportion of VFA enabling the animal to conserve energy.

Much of the VFA (>90%) is absorbed in foregut rumen, reticulum and omasal walls. Some may pass through the abomasum and be absorbed in the small intestine (about 80% VFA is absorbed in the rumen wall). After the VFA

absorbed by diffusion through the rumen wall they go to the portal blood circulation then to the liver.

Acetic acid is the major end product of carbohydrate digestion, in the ruminants. This VFA pass almost unchanged to the rumen wall to the liver which is little affect by the liver and goes to the peripheral blood or systemic blood in significant amounts. Acetic acid is used by a various tissues as a source of energy and synthesis of fatty acids.

Propionic acid passes across the rumen wall where a little is converted to lactate, the remainder carried to the liver where it is changed into glucose which may be changed to liver glycogen, or to fatty acids for triglyceride synthesis. The remainder of glucose goes to systemic blood supply and is carried to various tissues and used as source of energy or fatty acid synthesis, & for glycogen synthesis. Only a small amount of propionate present in the peripheral blood supply which can be used directly for energy production.

Butyric acid (butyrate) is changed in its passage across the rumen wall or metabolised by rumen epithelium to β -hydroxybutyric acid (BHBA) and passes into the portal blood then to the liver. The remaining small amount of butyrate that may appear in the portal blood will be removed entirely by the liver, leaving negligible amount in the arterial blood. BHBA pass liver to systemic blood and serve as source of energy and for synthesis of fatty acids in various tissue notably skeletal muscles.

Factors influencing the microbial digestion of fiber

The utilisation of fibrous feeds, cellulose and hemicellulose materials of fermentation are dependent upon many influencing factors. Some of them include:

1. One most important influencing factor is the kind and number of micro-organisms found in the reticulo-rumen, which has effect in rate of

fermentation of fiber. This in turn is under the influence of the character of the food. Example, Addition of easily fermentable carbohydrates, such as starch, cane sugar, molasses to ration of cattle reduces digestibility of the fiber as bacteria attack soluble carbohydrates preferentially.

The kind and number of microbes are different from one ruminant species to another and even within species it is possible to find varying numbers and kinds of microbes to utilise the fiber better.

2. The nature of the feed, this in turn may influence the kind & numbers of micro-organisms present in the reticulo-rumen. Starch fermenting bacteria or amylolytic bacteria increase with much soluble carbohydrates and cellulolytic bacteria decreases because of a decline in pH.
3. Stage of maturity of plants (degree of lignification), the complex polysaccharides in mature plants is less digested than they are in young, growing plants. The difference is mainly to the presence of certain substance notably lignin (cutin also), which are deposited in the cell wall with age. The degree of lignification affects digestibility of cellulose & hemicellulose. The lignin is not only indigestible itself, but it also lowers the digestibility of cellulose & other complex carbohydrates.

Lignin is resistant to attack by anaerobic bacteria, probably because of low oxygen content and its condensed structure which inhibits hydrolysis. Young pasture containing only 5% lignin, 80% cellulose may be digested but in older herbages with 10% lignin proportion of cellulose digested may be less than 60%.

Digestion of protein in the reticulo-rumen

Rumen microbes synthesise a large variety of **protein** and **enzymes** from different nitrogen sources, from proteins of varied nature and amino acid content, and from NPN compounds such as amines, ammonium salts, nitrates, uric acid, urea, etc. Monogastric animals could only utilise true protein but ruminants can also utilise NPN.

Food proteins of plants and animal origin are hydrolysed to polypeptides then to smaller peptides and amino acids by extracellular microbial proteases. The amino acids are degraded further by intracellular microbial deaminases to ammonia and organic acids, and CO₂.

The ammonia produced together with small peptides and amino acids is utilised by rumen micro-organisms to synthesise microbial proteins. 60-90 % daily nitrogen intake of ruminants is converted to ammonia, which is a preferred or essential source of nitrogen for rumen microbial protein synthesis. 60-80 % bacterial nitrogen is derived from ammonia, balance from amino acids or peptides.

NPN sources also readily degraded in the rumen to ammonia then to microbial protein. After this when the organisms are carried through to the abomasum and small intestine they will be digested by the proteolytic enzymes of the host and absorbed as amino acids. An important feature of the formation of microbial protein is that bacteria are capable of synthesising indispensable and dispensable amino acids, thus rendering their host independent of dietary supplies of the former.

Ammonia is an important intermediate in microbial degradation and synthesis of protein. If the diet contains less protein or protein resistant to degradation, concentration of rumen ammonia will be low (50 mg/l) and the growth of rumen microbes will be slow as a result breakdown of carbohydrates will be retarded. If protein degradation takes place more rapidly than synthesis, ammonia will accumulated in the rumen liquor and optimum concentration will exceed (85 to 300 mg/liter). But it is more realistic to relate it with to fermentable organic matter since for each kg of OM fermented a constant quantity of nitrogen is taken by rumen microbes for protein & nucleic acid. When ammonia concentration gets high, the ammonia which cannot be fixed in the rumen is absorbed through the rumen

wall and transferred in the liver to urea. Some of urea recycled back to the rumen via saliva, also directly through rumen wall but the greater part is excreted in the urine thus wasted.

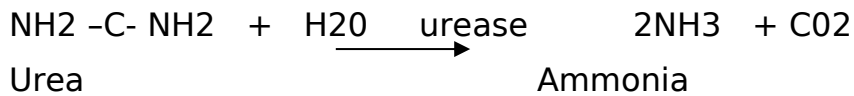
So when there is a high production of ammonia, it may accumulate in the blood (as liver will be overtaxed to convert all of it to urea) and is toxic, cause's ammonia toxicity. So this should immediately be converted to non toxic compounds by two means.

- ❖ By transferring ammonia to amino acids then to microbial proteins.
- ❖ Excess absorbed goes to portal blood then to liver where it is converted to urea which is non toxic as compared ammonia.

If the animal is supplied with excess nitrogen, there will be excess ammonia production which will be converted to urea in liver and animal has mechanism to remove excess urea by excreting it in the urine. But under nitrogen deficiency condition excretion of urea is decreased and quantity returned to rumen as urea exceed that absorbed from the rumen as much of the ammonia is converted to microbial protein. This means quantity of protein reaching the intestine may be greater than in the food. In this way ruminants are able to conserve nitrogen by returning to the rumen urea that otherwise be excreted in urine.

Then ammonia in the rumen is not supplied from proteins, but also as much as 30% of nitrogen in the ruminant food could be simple organic compounds such as amino acids, amides, amines or inorganic compounds such as nitrates. Most of these are readily degraded in the rumen to ammonia. In practice it is possible to capitalise the ability of rumen microbes to convert NPN to protein, by adding such NPN compounds to the diet. The substance most commonly employed is urea. Ammonium salts may also be used.

II



Urea entering to the rumen is rapidly hydrolysed to ammonia by bacterial urease, and rumen ammonia concentration is liable to rise considerably. For this ammonia to be efficiently incorporated into microbial protein, two conditions must be met.

1. The initial ammonia concentration must be below the optimum (otherwise ammonia may be lost).
2. Micro-organisms must have a readily available source of energy for protein synthesis.

Feeding practice intended to meet these conditions include mixing urea with other foods to prolong the period over ingested and deaminated and also to provide energy sources having rate of fermentation comparable to urea. Such foods should be low in rumen degradable protein, and high in readily fermentable carbohydrates.

Another NPN which can be utilised by ruminants is uric acid which is present in high concentration in poultry excreta. So these are sometimes dried for inclusion in the diet of ruminants. 60-90% the daily nitrogen intake of ruminants is converted to ammonia in the rumen for synthesis of microbial protein. The other 10-40 % could directly pass to lower gut without being fermented in the rumen called bypass protein or undegraded dietary protein (UDP). The other is rumen degradable protein (RDP). Resistance of protein varies between the protein sources as some proteins are resistant to microbial attack but digested in the lower gut by enzyme of the host. So bypass proteins are proteins that pass without degradation in the reticulo rumen.

As a consequence of their forgut fermentation, ruminants are provided with two major sources of proteins.

1. The protein synthesised by the microbes (microbial protein), and
2. The UDP, which escapes microbial digestion in the rumen. Digestion of these two mixtures of microbial protein & UDP in the abomasum and small intestine supplies the amino acid for the host animal.

The bypass protein in animal feeding has got practical implication. There is a measure of protein quality called biological value (BV). BV is measure of proportion of food protein which can be used by the animal for synthesising body tissues and compounds which is defined as proportion of nitrogen absorbed that is retained by the animal.

If you compare BV of microbial protein with plant and animal protein sources, BV of microbial proteins is about 80%, protein of plant origin generally has less than 80% BV and proteins of animal origin like fish meal, meat meal has greater than 80% BV. This means animal origin protein sources are better than microbial proteins. Whatever protein source supplied to rumen microbes, they will change it to microbial protein.

If supply plants proteins having less than 80% BV, the micro-organisms change it to microbial protein of 80% BV means upgrade the protein quality. If on the other hand supply animal proteins like fishmeal (95% BV), it will be changed to 80% BV degrading the quality of protein. Therefore, there is no need of feeding ruminants with high quality protein as it is a loss, but use high quality proteins mostly to monogastrics.

Protein supplements are generally the most expensive ingredients in ruminant ration. Thus there is an interest maximising their utilisation. Post ruminant infusion or supplementation with good quality protein sources protected from rumen fermentation by some means has resulted in improved nitrogen retention & animal performance, as rumen microbial protein synthesis may reduce maximum utilisation of high quality dietary proteins. Therefore making some quality proteins bypass for lower tract

digestion by treatments like mild heat treatment, chemical such as formaldehyde or tannins is helpful.

Digestion of lipids in the reticulo-rumen

Compared to carbohydrates and proteins, lipid comprise small but non negligible proportion of ruminants diet with the lipid content of forages ranging up to 3%. In fact in ruminant diets fat content in excess of 2-3 % of feed DM are inhibitory to microbial activity in the rumen. Lipids for ruminant animals are basically three types

- ❖ Galactolipid, found in grasses and clovers which form major dietary fat of ruminants.
- ❖ Triglycerides most abundant in seeds of plants. So it is important when animals are fed concentrates.
- ❖ Phospholipids, feeds like soybean has high amount of phospholipids.

The galactolipids will be hydrolysed by bacterial lipases into free fatty acids, glycerol and galactose. Triglycerides into free fatty acid and glycerol, Phospholipids are hydrolysed into fatty acids and glycerol with phosphate attached. After this secondary type of reaction takes places, Galactose is a monosaccharide, so will be converted to VFA (acetic, propionic, butyric). Glycerol is a three carbon compound (trihydroxy alcohol), so it will be changed to propionic acid not to acetic (C2) and butyric (C4) compounds.

The principal fatty acids in lipids fed to ruminants via plants include linoleic, linolenic and oleic acids. Once they are released from **ester** combinations the unsaturated fatty acids (linolic & linolenic) are rapidly hydrogenated by microbial enzymes that can affix 'spare' atoms of hydrogen to the carbon chain of unsaturated fatty acids, first to monoenoic fatty acids and the to form their saturated analog stearic acid, as the intraruminal environment is a highly reduced one containing lot of free floating hydrogen. Therefore in the reticulo-rumen lipid digestion results in the formation of two basic end products saturated fatty acids and VFA. Unlike the short chain VFA, long

chain fatty acids are not absorbed directly through the rumen wall rather goes down to the lower tract being attached with feed particles or associated protozoa or bacteria. This will enter small intestine where it is digested by enzyme of host and absorbed. Eventually ruminants use this for energy, synthesis of its own fat depots or for milk fat synthesis.

The hydrogenation of fatty acids in ruminants explains why a large proportion of the fatty acids in tissue fat from ruminants or the milk fat of ruminants are saturated. For non ruminants it is possible to vary the fatty acid composition of body fats by altering dietary fats. Not for ruminants unless they are provided with rumen protected fats.

Bacteria and protozoa are also capable of synthesising a number of odd chain fatty acids from propionic acid (C3) and branched chain fatty acids from the carbon skeleton of the amino acids valine, leucine, & isoleucine which are also incorporated in milk and body fat of ruminants contributing to the characteristic composition of ruminants tissue lipids.

The capacity of the rumen microbes to digest lipids is strictly limited. Although gross energy content of fats is higher than any other component of the diet, unfortunately large amounts of fatty acids in the rumen can have series effect on the ability of microbes to breakdown other components of the diet. **Saturated** fatty acids affect rumen fermentation less than do the **unsaturated** once.

4.3. Metabolism of nutrients

Metabolism is a general term given to the sequence of chemical processes that take placed in the living organism. These reactions continue as far as the living body exists. These processes can be categorised into three

1. Anabolism; describes the metabolic processes in which complex compounds are synthesised from simpler substances.

2. Catabolism; describes metabolic processes that involve the degradation or breaking down of complex compounds to simpler molecules.
3. Waste product transformation; as a result of the above two metabolic processes, waste products arise which has to be chemically transformed and ultimately excreted. The reactions necessary for such transformation form the general part of metabolism. Example, when protein is catabolized, ammonia is liberated which cannot be excreted as it is. It has to be transformed into urea which is categorised as 3rd type of metabolism.

The starting points of metabolism are the substances absorbed after the digestion of food. For all practical purposes we may regard the end products of carbohydrate digestion in the simple stomached animal as glucose, together with very small amounts of galactose and fructose. These are absorbed into the portal blood and carried to the liver.

In ruminant animals, the major part of the carbohydrate is broken down in the rumen to acetic, propionic and butyric acids, together with small amounts of branched-chain and higher volatile acids. Digestion of proteins results in the production of amino acids and small peptides, which are absorbed via the intestinal villi into the portal blood and are carried to the liver, where they join the amino acid pool. They may then be used for protein synthesis *in situ* or may pass into the systemic blood, where they join the amino acids produced as a result of tissue catabolism in providing the raw material for the synthesis of proteins and other biologically important nitrogenous compounds.

5. Nutritional disorders and Anti-nutritional factors

Those disorders which are due to nutritional deficiencies, such as milk fever, lactation tetany, ketosis, pregnancy toxemia of ewes, bloat, ingestion etc.

These diseases are not due to the infection or toxic agent but due to the disturbance in the normal metabolism in the animals.

1. Indigestion or acidosis: Sudden change in the dietary of animals on high grain feeding of wheat, corn etc. leads to acute and fatal indigestion in ruminants. Feeding ruminants on large quantities of grains containing soluble sugars leads to massive production of lactic acid in the rumen as a result of rumen fermentation. The accumulation of lactic acid in the rumen as a result of fermentation causes the pH to fall between 4-5 in extreme cases. Under these conditions the rate of absorption of VFA is increased but lactic acid absorption is unaffected. An acidic condition in the rumen inhibits the normal contractions of reticulum and rumen which affects the speed with which food passes to abomasum and intestine. Cattle fed entirely on concentrates without any roughage develop acidosis. This can be ascertained by the determination of pH of the urine which is between 5 & 6. This indicates that acid-base equilibrium of the animal has been disturbed as the normal animal should have pH between 7-8. The animals should be introduced on grains gradually to high grain and low roughage diets rather than a sudden change. If the animal survives the initial acute acidosis, the animal still exhibits symptoms of loss of appetite. This is due to modification in rumen microflora, damage to the rumen epithelium etc. For treatment large quantities of sodium bicarbonate in isotonic solution are given, by mouth. Thiamine administration may also be beneficial as it metabolizes the lactic acid.

2. Bloat (Tympanitis): In the bloat the rumen is dilated with gas (CO_2 and CH_4). Bloat is characterized by the distension of the rumen by a foaming mass of contents which the animals cannot eliminate by belching. Bloat is generally observed in cattle while grazing the pastures in monsoon and eating clovers like alfalfa. As they are consumed in large quantities. Presence of cyanogenic glycosides, saponins, metallic ions like nickel, zinc present in red clover are the factors responsible for formation of foam in the rumen. It is clear that soluble sugars of green fodders are easily and rapidly fermented

which lead to rapid accumulation of VFA, CO₂ and CH₄ which cause the bloat. Slow absorption of VFA and slow eructation of gas lead to tympany. The rumen distention impedes the blood flow and anorexia develops which is responsible for respiratory failure. To prevent the bloat- feed 1-2 kg of wheat straw with green fodders. Antibiotics per os have been effective in reducing the bloat. Turpentine and paraffin oils also helpful in reducing bloat.

3. Milk Fever (Hypocalcaemia): There are many factors for milk fever in which the calcium level in the blood falls down. In high producing cow and buffalo immediately after parturition, the calcium level goes down so much that animal becomes unconscious and dies if treatment is not given. Not only Ca but sometimes P level also goes down. Calcium gluconate injection improves condition. This condition is more common in cross-bred and exotic cows as they are high producing animals.

4. Hypomagnesaemia: This condition is a result of Mg deficiency in the diet and leads to muscle tremors/tetany. It is more common in grazing cows and is often known as grass tetany. Intravenous or subcutaneous injections of Mg chloride or Mg sulfate are generally given to alleviate the condition.

5. Ketosis: This is a condition in which aceto-acetic acid, beta-hydroxy butyric acid and acetone accumulate in the blood due to impaired metabolism. In cattle it is observed in early lactation and in sheep in the last month of pregnancy especially when they are carrying twins and triplets. Ketone bodies are formed in fasting condition where body reserves of fats are utilized for energy purposes. The acetyl coenzyme A which is a potential source of ketones is formed due to oxidation of all the nutrients. It enters the TCA cycle by combining with oxaloacetate. Due to increase in demand of mammary glands or fetus for glucose, the oxaloacetate supply is reduced due to which there is overproduction of acetyl CoA which then cannot enter the TCA cycle at a rate at which it can be oxidized, therefore ketone bodies are formed. In ruminants propionate is the principal source of CHO precursor,

is increased during pregnancy and lactation and diet is unable to supply. In this condition butyrate is formed in the rumen which is ketogenic. Due to disturbed endocrine system also large quantities of acetyl-CoA are formed. Intravenous injection/administration of dextrose solution has been found to be effective.

Diagnosis: The common test is to determine the ketone bodies in Blood, Urine and Milk. The normal levels of blood = < 10 mg/ 100 ml, but may go upto 50-100ml in affected animals. Milk = $\frac{1}{2}$ of that of blood

Or = $\frac{1}{8}$ th of urine

6. Post Parturient Haemoglobinuria: P deficiency haemoglobinuria has been reported in mature dairy animals. P supplements reduce the incidence of this disease.

7. Urea/Ammonia Toxicity: Increased intake of urea fed as feed supplement in the diet of ruminants may cause urea toxicity. This is due to the high ammonia circulation in the blood which the liver can not detoxify, vinegar; dilute acetic acid (5% solution), ice-cold water be offered, which may be helpful in reducing the toxicity.

Anti-nutritional Factors

Certain animal feedstuffs and forages contain substances which can significantly reduce their nutritive value. They are called as toxic factors, as they produce deleterious effects when consumed by animals. The term toxic factors are misleading because these substances are lethal beyond a certain level of intake. In most animals they produce lesser effects e. g. reduced growth, poor FCR, hormonal changes and organ damage. Better to call them ANF's (Anti-nutritive factors/substances). They are defined as "those generated in natural feedstuffs by normal metabolism from which the

material originates by different metabolism, decomposition or inactivation of nutrients, digestive disorders or metabolic utilization of feed, exert effects on optimum nutrition". Artificial antagonists are different than ANF's, for example when preservatives or other chemical additives, which can inactivate or destroy certain nutrients; toxic compounds which may result from different manufacturing processes: like pesticides, herbicides and mycotoxins. These are classified on the basis of type of nutrients they affect, either directly or indirectly, and the biological response produced in the animals.

1. Substances depressing digestion or metabolic utilization of proteins:

1. Protease inhibitors

2. Lectins

3. Saponins

4. Polyphenolic compounds

1. Protease inhibitors: Feeding raw and unheated soybeans to rats produced poor growth and food conversion. These effects were over come by heat treatment of soybeans, which improved the nutritional value. Protease inhibits the proteolytic activity of certain enzymes.

Nutritional significance: Growth depressing effect in rats was due to slow release of methionine by proteolytic enzymes in the presence of trypsin inhibitors, so absorption of methionine was delayed. In chicks, feeding of raw soybeans developed hypertrophy of pancreas. In calves, pigs and dogs, hypertrophy of pancreas was not observed. Other studies revealed that the growth depressing activity of trypsin inhibitors could be due to excessive endogenous loss of essential amino acids derived from the hyperactive pancreas. This effect could be corrected by supplementation of amino acids.

Effect of processing and quality control: Protease inhibitors are destroyed by heat treatment. The different methods of heat treatments that can be employed are: 1) moist heating (cooking and autoclaving), 2) Dry heating, 3) Extruding and 4) Infra-red cooking or micronization. The important factors controlling trypsin inhibitors destruction are temperature, duration of heat, particle size and moisture level. Over heating leads to damage of amino acids and vitamins. Quality control can be maintained by determining the inhibitors by different methods like

- a) Urease assay
- b) Trypsin inhibitor
- c) Cresol red absorption,
- d) Protein dispersibility index (PDI) and e) nitrogen solubility index (NSI).

The first accurate method for assaying trypsin inhibitor was developed by Kakade et. al. (1974), in it a “trypsin unit” and inhibitory activity was expressed in terms of trypsin unit inhibited (TUI)/ mg of sample. Kakade method was modified by the American Association of Cereal Chemists (AACC, 1981), and good correlation was found between trypsin inhibitor activity, cresol red absorption, PDI and NSI ($r = 90\%$).

2. Lectins (Haemagglutinins): First lectin was found in 1889 while studying the toxicity of castor bean cake after oil extraction by Stillmark. The toxic agent was named as “Ricin”. The ricins agglutinate human red blood cells. Lectins are proteins and have affinity for sugar molecules like soybean lectin for mannose. They are found in seeds, but some are also found in tubers.

Toxicity: When soy lectin was injected in weanling guinea pigs, caused death but not in rats. When administered per se, the stomach pepsin inactivated rapidly, the microflora of GIT may convert lectin to certain toxins. Lectins

attach to the cells lining the intestine wall, cause interference with digestion of nutrients and particularly of proteins digestibility.

3. Saponins: They are the glycosides and are present in plants, and are bitter in taste, foaming in aqueous solutions and haemolysis of red cells. On hydrolysis, they yield sapogenins which are either steroids or triterpenoids and sugars. The haemolysis of red blood cells is due to interaction with cholesterol in the erythrocyte membrane.

Effects on animals: Poultry is much sensitive than pigs. 20% Alfalfa in poultry diet produce significant growth depression (0.3% saponins). In ruminants, the saponins undergo bacterial degradation in the rumen and have no growth depression effects.

4. Polyphenolic compounds (Tannins and chlorogenic acid): They are the tannins and defined as Polyphenolic substances with 500 molecular weight. They are degraded by enzymes, yielding sugar and phenol carboxylic acid. High content of tannins cause reduced protein and dry matter digestibility, because tannins interfere with digestive action of trypsin and alfa-amylase, by binding the enzymes, themselves or by combining with protein to form indigestible complex. Chlorogenic acid is a Polyphenolic compounds which occur in sunflower seed meal (1.2%) which cause growth depression and efficiency of feed utilization in mice, by inhibiting enzymatic activity of proteinase, amylase and lipases.

2. Substances reducing the solubility or interfering with the utilization of mineral elements:

1. Phytic acid
2. Oxalic acid
3. Glucosinolates
4. Gossypol

1. Phytic acid: Phytic acid is a cyclic compound containing six phosphate groups (inositol-hexa- phosphoric acid). The phosphoric acid may contain one metal or mixed metals like Ca, Mg, Zn, Cu and Fe, and known as chelates. The chelates are insoluble and not absorbed from the GIT. Phytic acid and metal phytates are decomposed by the enzyme called phytase, which is present in plant tissues. In pigs and chicken, phytate phosphorus utilization is poor, with reduced intestinal absorption of P and Ca. In sheep and cattle, phytic acid is hydrolyzed by the ruminal microbes, thus no problem. High level of phytic acid in monogastric can reduce the absorption of Ca by 35%.

2. Oxalic acid: Oxalic acid is found in vegetables and animal kingdom. Plants are rich in oxalates are beet, spinach etc. the oxalic acid form a complex with calcium and does not allow to absorb it. Rumen microbes can split of Ca and decompose the oxalic acid. In pigs and poultry, if spinach is fed, it will cause depression in growth and reduce the Ca retention.

3. Glucosinolates (Thioglucosides): They are present in mustard and horse-radish, which is pungent in flavor. Main effect is that they depress the synthesis of thyroid hormones, and produce "Goiter". When cattle and sheep graze on these pastures, produce enlarged thyroid glands due to deficiency of iodine. These compounds occur in root, stem, leaves and seeds and always accompanied by thioglucosidase enzyme, hydrolyzing into glucose, acid sulphate, thiocynates or isothiocyanates. In the thyroid condition, the suppressing effect of these substances is due to their reducing the incorporation of iodine into the thyroxin, and interfere the secretion. In poultry, liver haemorrhage is reported by feeding rape seed meal. In pigs, feeding 10-20% rape seed meal produced growth depression, hyperplasia of thyroids and enlargement of liver and kidneys. Ruminants are less susceptible to toxic effect.

4. Gossypol: gossypol is found in the pigment glands of the cottonseed. The toxicity of gossypol is normally occurring in monogastric and the horses and

ruminants are resistant to its toxic effect, as microbes hydrolyze it. Presence of gossypol reduces the availability of lysine amino acid. Heat treatment is a commercial method of reducing gossypol in cottonseed. The plant breeders may evolve the cotton variety, which are glandless, so that no such toxic factor is present.

3. Substances inactivating or increasing the requirements of certain vitamins:

1. Anti-vitamin A, D, E and K

2. Anti-thiamine, nicotinic acid, B₆ and B₁₂

1. Anti- vitamin A, D, E and K: Raw soybean contains Lipoxygenase enzyme which destroy the carotene (Precursor of vit. A). The activity of this enzyme can be destroyed by heating the raw soybean. The protein isolated from raw unheated soybean can produce rickets in turkey, which can be corrected by feeding heated soybean. The diets having kidney beans can produce muscular dystrophy (produced by vit. E deficiency) in chicks and lambs. This disorder can be eliminated by addition of vitamin E or by autoclaving the beans. Sweet clover disease is produced due to the presence of dicumarol, which reduces prothrombin level of the blood and interfere with blood clotting. Dicumarol is a refractory substance and is antagonistic of vitamin K, which reduces the vitamin K utilization.

2. Anti-thiamine, nicotinic acid, pyridoxine (B₆) and Cyanocobalamin (B₁₂): Thiaminase is anti-thiamine factor, present in fern and raw fish. Anti-thiamine activity has been reported in rice bran, mustard seed, cotton seed etc. Supplementation of Nicotinic acid in the diet prevents pellagra disease. Feeding of high-maize diet can produce pellagra in dogs, apes and pigs. L-amino-D- proline is antagonist of B₆ vitamin and is present in linseed, which occur naturally in combination with glutamic acid as a peptide called Linatine. Raw soybean contains heat-labile substance which increases the requirement of B₁₂ vitamin.

HCN

Cyanides: HCN is present in grasses, pulses and root crops like cassava. Linseed contains 53 mg HCN/100 g and can cause poisoning. Ruminants are more susceptible to HCN poisoning than horses and pigs, because in horses and pigs HCl is produced in stomach, which destroys the enzyme releasing HCN. HCN may cause convulsions, respiratory distress in cattle. Sheep is less susceptible than cattle to HCN.

Anti-nutrients present in feed stuffs and their impact on performance

S.N.	Anti-nutrients	Occurrence	Effect
1	Trypsin inhibitors	Soybean seeds	Reduced growth, low production, pancreatic hypertrophy
2	Haemagglutinins (Lectins)	Soybean seeds	Decrease in protein utilization, poor growth
3	Glucosides		
	a) Saponins	Soybean seeds,	Increases respiratory rate, Inhibit activity of certain enzymes, low growth, lowered egg production.
	b) Glucosinolates	Rape /mustard Seed	Goitre, poor growth, lowered egg production, liver hemorrhages, fatty liver
	c) Estrogens	Soybean seeds	Poor growth, increased zinc in liver and bone, increase deposition of Ca, P and Mn in bones
4.	Phenols		
	a) Gossypol	Cotton seed Meal	Poor growth, low feed intake, ascites, cardiac irregularity, reduced oxygen carrying capacity of the blood, olive green discoloration of yolk in layers.
	b) Tannins	Sorghum, rape / mustard meal	Reduced growth, poor egg production
5.	Phytate	All vegetable Feed ingredients	Increased requirement of phosphorus and trace minerals
6.	Erucic acid	Rape /mustard seeds	Poor growth, low feed intake, poor feed efficiency
7.	Argemone	Adulterated rape / mustard seed meal	Swelling of legs, diarrhoea, atrophy of optic nerve, edema

Chapter 6

Evaluation of Feedstuff

6.1 Analysis of chemical composition

The nutritive value of feedstuff is determined by different methods. Feed quality assessment can be achieved through its **chemical composition, digestibility** and **palatability** parameters. The analysis provide useful information about feed harvesting and sorting methods, thus helping to obtain the highest quality feed for animals and the most profit to produce. Feed chemical composition assessment can establish the ground how potent feedstuffs are in supplying the nutrient for the animals. Feed chemical composition is vary depending up on number of factors such as stage of plants maturity, processing methods, the genetic make-up of the plants, the growing soil condition and damage associated with insect.

Feed analysis provides information for:

Farmers to optimize nutrient utilization in animal feeds;

Feed compounders to prepare feed mixtures suitable for different animal production systems;

Researchers to relate animal performance to feed characteristic; and

Plant breeders to optimize the nutritive value of new varieties.

6.1.1. Proximate analysis system

In 1865 Henneberg and Stohmann developed a scheme for describing the approximate chemical analysis system at Weende Experiment Station in Germany. Under this scheme various nutrients that had some common properties were grouped together and analyzed. These nutrients are known as proximate principles of feed and the analysis as proximate analysis. The method is based on the separation of feed components into fraction or groups in accordance with their feeding value. In this system of analysis, feedstuff is analysed into six fractions (water, ether extract (EE), crude protein (CP), crude fiber (CF), ash and nitrogen-free extract NFE)). All the proximate principles are determined by different methods/procedures except NFE which is determined by difference. Except for water, other results in proximate principles are expressed on dry matter (DM) basis.

➡ Steps involved in obtaining and preparing samples

1. Obtain a small quantity from several locations within a lot of feed.
2. Insure that samples are randomly selected and sufficient in amount.
3. Finely grind or chop the sample and mix until each spoonful is representative of every other spoonful within the given lots of feeds.
4. Keep the sample in a tightly closed container or refrigerate if necessary to avoid further change in chemical composition.

1. Water/Moisture

Water is the simplest of all substances in feeds, but not the simplest to determine. Usually it is recorded as the loss in weight of the sample as a result of oven-drying it to a constant weight at atmospheric pressure and at a temperature just above the boiling point of water. For many biological products such as moist feeds and the excreted feed residues, such drying results in loss of volatile fatty acids, and of some sugars that decompose at temperatures above 70°C. Such substances will

obviously be counted as water. The significance of water content of feeds depends on the kind of feed and the amount of water.

➡ Procedure for determining the water content

Weigh a small amount of the sample into an appropriate container (W1)

Drying a feed sample in appropriate an oven set at 100-105°C for 12-24 hours

After drying to a constant temperature, weight the sample residue (W2) and calculate per cent of water content.

$$\% \text{ Water} = \frac{W1 - W2}{W1} \times 100 \text{ or } \frac{\text{weight lost upon drying}}{\text{sample weight}} \times 100$$

Once the moisture content of the feed is determined, the dry matter content of the feed sample is calculated as the difference of water content from 100 as broadly feed is partitioned into dry matter and water part. In the procedure of moisture determination, some feedstuff such as silage contains volatile compounds, so at high temperature of drying, it loss the volatile compound as a water portion which over estimate the value of water content and underestimate their dry matter value as the volatile compounds are not water origin. Such type of feed should be freeze dried or vacuum oven dried. Moreover, when green feeds are dried at high temperature, lignin and nitrogen complex is formed and exaggerate the fiber component of the sample. Therefore, such types of feeds are needed to be determined on two stage dry matter determination at temperature 60- 65°C for about 72 hours. In the two stage procedure partial dry matter as well as dry matter of partially dried samples are need to be determined while the product of the two value give us actual dry weight the samples have at it fresh base sampling. Generally, the absolute value of the feed dry matter is less than value for partially dry weight and dry matter of partially dried samples.

$$\text{Actual DM} = (\% \text{PDM}/100) \times (\% \text{DMPDM}/100) \times 100$$

Some definition of terms related to Dry matter

As fed base, as is base or wet base: it refers to the forage of feed as it is consumed by the animals. In this case the dry matter may range from 0-100%.

Air dry basis: refers to a sample that has been allowed to dry in air without aid of oven. Its dry matter may go up to 90% in this system.

Dry Total Dry Matter: refers to a sample that has all of the moisture has been removed. Forage and other feedstuffs analysis should be done on DM basis

To convert values from a DM basis to a wet-weight basis or as is basis use a formula:

$$\text{As is basis} = \frac{\% \text{ DM} \times \text{Nutrient on DM basis}}{100}$$

To convert from wet-weight to dry weight basis use formula:

$$\text{Dry weight basis} = \frac{100 \times \text{Nutrient on wet-weight basis}}{\% \text{ DM}}$$

2. Ash

Ash is the inorganic residue from the burning of a sample at about 500- 600°C. Ash embraces the most part of the inorganic or mineral composition of the feed. Relatively, the ash content from plant material is a poor index of any of the inorganic nutrients due to their high variability. On ignition all the organic matter is oxidized and inorganic matter remains. The problem in ash determination is that certain minerals (Se, Pb, Cd) may be volatile by high temperature ashing. For such problem wet ashing, which involves digestion of the sample organic matter with nitric acid and perchloric acid is used. The part of ash which is soluble in an acid is known as acid soluble ash (inorganic elements) and insoluble portion in acid is known as acid insoluble ash (silica). The higher is the acid insoluble ash in the feed sample, the poorer is the quality of a feed. The analysis of ash may not give us meaningful information as it tells us nothing of specific mineral content. Ashing is generally a preparatory step for further analysis of specific minerals by spectrophotometer or atomic absorption techniques.

Procedure

Weight small quantity of the prepared sample into a small crucible

Ignite the sample in muffle furnace at 600°C for 2 hrs.

Weight the ash with its crucible

Calculate the % mineral or **%Ash= $\frac{\text{Weight remain in crucible}}{\text{Sample weight}} \times 100$**

Sample weight

NB: Once the ash value was known, ash minus 100 will give us the organic matter portion.

3. Ether extracts (EE)

This is a group that insoluble in water and soluble in organic solvent such as ether, chloroform and benzene. This group is also called crude fat due to non-fat origins are soluble in the organic solvent and included as fat part. Ether extract or crude fat is estimated by extracting the known amount of feed sample through fat solvent for a time of specific hours, 8 hrs, at 55°C to 60°C in specially made soxhlets apparatus. The weight of the residue left after evaporation of the solvent is called ether extract or also determined as loss in weight of the moisture-free sample following its extraction by anhydrous ether. Though other ingredients are there in the solution the largest portion is mostly lipid. Ether extract is differ in composition among different feeds and an indicative of the energy measure of feeds. Digestible EE contain 2.25 times more energy than carbohydrates and proteins and yields 9.35 kcal of gross energy or approximately 9 kcal/gm of metabolizable energy as consumed in the diet. Nutritionally, fat is used to increase the energy density of a feed.

Problems with EE:

Ether extract may contain ingredients which are not fat origin (chlorophyll, fat soluble vitamins, resins, wax, organic alcohols, alkalies, pigments and other)

Extraction of lipids by fat solvents can be complicated by: lipids may be linked with proteins and carbohydrates and the complexes are usually insoluble in fat solvents, some lipids are only soluble in limited range with fat solvents, some fat solvents are also good solvents for certain non-lipid constituents (e.g., acetone, alcohol are effective extractants of urea, amino acids, sugars).

Procedure:

Remove water from the sample to be used for extraction to facilitate the thorough penetration of the solvent chemicals to the sample to solublize it.

Weight out small quantity of the dried sample and place it in the extraction thimble.

Extract the sample with ether in a soxhlet extractor for 8hrs

Evaporate the ether from the extract and weigh the remaining weight

$$\%EE = \frac{\text{Weight of EE} \times 100}{\text{Weight of the sample}}$$

4. Crude Fiber

According to proximate analysis crude fiber refers to the residue of a feed that is insoluble after successive boiling with dilute alkali and dilute acid in accordance with the procedures originally proposed by the Weende Experiment Station. Crude fiber is the portion of the total carbohydrate of a feed that is resistant to the acid and alkali treatment and represented an indigestible portion of the feed. Probably, this may be a misleading index of the overall digestibility of a feed, for the simple reason that in an appreciable number of cases the crude fiber itself is at least as highly digested as the soluble carbohydrate usually referred as NFE. The reason for the relatively high digestibility of crude fiber by the ruminant animals lie in the fact that the largest component (perhaps 95%) of the crude fiber is cellulose, and it is known that the microorganisms of the rumen are able to break down cellulose for their own needed energy, and that in the process they produce acetic (and some butyric and propionic) acid, which is absorbed from the rumen and supplies energy to the host animals.

Procedure:

Weight out small quantity of prepared sample (W1)

Boil the sample in dilute H₂SO₄ for 30 minutes and filter. Then boil in dilute NaOH for another 30 minutes and filter it. These extraction removes protein, starch, sugars, more soluble hemicellulose and minerals and possibly some lignin

Dry the residue and weight (W2) this residue contain CF and insoluble mineral matter

Ash the residue to oxidize off the CF and weigh the ash (W3)

$$\%CF = \frac{W2-W3}{W1} \times 100$$

5. Crude protein

Protein always seems to be in short supply, so a good estimate of the protein content is vital in diet formulation. Determined by Kjeldhal procedures after the Danish Chemist Johan Kjeldahl developed it in 1880's. In the procedure, protein is not directly measured but nitrogen is determined and multiplied with conversion factor to estimate the protein value of the feed. Probably the protein content of a feed is also an indirect measure of its digestible energy, because the protein component of feeds is usually highly digested as compared with the coarser carbohydrates. Consequently, forages that are high in protein are almost sure to be correspondingly lower in CF. To a limited extent this holds true for concentrated feeds. Two assumptions are necessary to be considered in crude protein determination procedure: all nitrogen in the feed is assumed to be exist in the form of protein and protein contain on average about 16% nitrogen. However, both of these assumption is not hundred per cent correct, as a result the assumption are used with their limitations.

Short coming in crude protein estimation:

It is crude because not tell us whether the **N** is in the form of amino acids, true protein or **NPN** (urea, nucleic acids, amines etc). The problem may be in lush pastures and fermented feeds as they may contain more **NPN**.

All proteins do not contain 16% **N**. Milk protein contains 15.7% **N** so a protein factor 6.38 should be used. Most oil seeds and wheat bran contain 18.3% **N**. So we are overestimating the protein for wheat bran and underestimating for milk by using the protein factor of 6.25. This is due to the fact that as **N** content of the feed increase than 16% then protein factor should be decline.

Protein determination procedures have three phases:

- I. ***The digestion phase:*** in this phase the feed sample will be digested by concentrated H_2SO_4 in the digestion tube to oxidize organic material to CO_2 and H_2O . The digestion requires a temperature of about 350°C . Different catalysts are used in the digestion phase such as potassium/sodium sulfate (to raise the boiling point of H_2SO_4 and increase rate of digestion) and mercuric oxide, copper sulfate or selenium (to assist in the reduction of **N**). In the process **N** in the feed sample will be changed to ammonium sulfate- $(\text{NH}_4)_2\text{SO}_4$.

- II. Distillation phase:** in this phase the digested product $((\text{NH}_4)_2\text{SO}_4)$ will be cooled, diluted with water and made strong with basic solution of NaOH, the addition of the base in this phase liberates ammonia from the sulfate form. The distilled ammonia gas will be trapped by boric acids as ammonia is volatile substance.
- III. Titration phase:** in this phase the quantity collected will be determined by titration or automated colorimetric method. It is simply neutralizing the ammonia with a standard acid (HCl or H_2SO_4). The acid is formulated so that 1ml of the acid will neutralize 1 mg of **N**. Once ml of the acid used for titration are known, **N** content can be easily calculated.

NB: with the procedure of **N** determination, a blank sample should be run with the system to estimate the blank volume to account for **N** that is not from the sample origin.

$\%N = 1.401 (\text{Volume of titrant} - \text{Volume of the blank}) \times \text{Normality of the acid}$

Sample weight taken for analysis

$$\%CP = \%N \times 6.25$$

6. Nitrogen Free Extract (NFE): this part is determined by difference rather than following specific system. As a result, the deduction of the above five fraction from hundred give us the NFE portion of a feed. **$NFE = 100 - (\text{water} + \text{ash} + EE + CF + CP)$**

6.1.2 The Van Soest Method of Forage Evaluation

While the Weende system of feed analysis has served for many years and continues to serve as a useful purpose in predicting the nutritive value of feeds, this does not mean that the system is without its short comings or is not in need of improvement. In fact, there are some definite limitations of the Weende system, especially with respect to CF and NFE.

Crude fiber is not a chemically uniform substance but a variable mixture, the major components of which are **cellulose, hemicellulose and lignin**. Cellulose and hemicellulose are similar in nutritive value; they have much greater feeding value

for ruminants than for non-ruminants. Lignin is essentially indigestible by all livestock. The fact that complicates the situation of CF is that only a part of the hemicellulose and lignin comes out in the CF fraction, with the remaining partitions showing up as NFE, which is ordinarily thought of as consisting largely of highly digestible sugars and starches. Consequently, to the extent that hemicellulose at best low in digestibility and lignin essentially indigestible appear in the NFE fraction, this fraction would be larger and have a lower average digestibility than would be true if it consisted primarily of sugars and starches. At the same time, the CF value would not reflect the entire more indigestible portion of the feed.

As a result, numerous workers over the past several years have tested various procedures which might provide a more definitive separation of feed carbohydrates than does Weende system of proximate analysis. Van Soest consider a wider possible substitute for the conventional CF determination, it involves the separation of feeds dry matter into two fractions: high digestible fraction and low digestible fraction by boiling the feed in neutral detergent solution (3% sodium sulfate buffered to pH 7 for one hour and filtering).

The neutral detergent soluble (NDS) consists most of the cell contents of the feed which composed of lipids, sugars, starches and proteins. All are high in digestibility, having true digestibility of about 98%. Their digestibility does not seem to be materially influenced by the amount of neutral detergent insoluble present. The neutral detergent insoluble is usually neutral detergent fiber (NDF). They embrace most part of plant cell wall or referred to as the cell wall components or cell wall constituents. They consists cellulose, lignin, silica, hemicellulose and some damaged proteins.

In the Van Soest procedure essentially, all of the lignin and hemicellulose are included in the NDF fraction, where as with the Weende methods variable amount these two components are lost from the CF to the NFE. As a result, NDF as determined by the Van Soest procedure is considerably higher than the conventional CF values for the same feeds. The different NDF components are at best low in digestibility and are entirely dependent on the microorganism of the digestive tract for any digestion they do undergo. Lignin and silica are essentially

indigestible even by microorganisms. Also, lignin has a curvilinear negative influence on cellulose and hemicellulose digestibility. NDF corresponds more closely than does conventional CF to the total fiber fraction of a forage feeds. For the purpose of determining the lignin in the forage, Van Soest has proposed the use of what has come to known as the acid detergent lignin procedure.

Acid detergent fiber differs from NDF in that NDF contains most of the feed hemicellulose and limited amount of protein not present in ADF. Therefore, the difference in the amount of NDF and ADF is an estimate of hemicellulose. To determine the lignin present, ADF should be digested in 72% H₂SO₄ at 15°C for 3 hours then filter and dry in oven. The remaining residues are lignin and silica. Then ash the residue, the ash remaining approximates the silica present, while the lost in weight during ashing approximates the lignin and referred to as acid detergent lignin (ADL) or more specifically as acid insoluble lignin.

Remark: Once the NDS, NDF, ADF and ADL have been determined for forage feeds, the true digestibility of the forage dry matter may be estimated by using the following equation:

$$\text{True digestibility} = 0.98\text{NDS} + (1.473 - 0.789\log_{10} \text{lignin}) \text{NDF}$$

6.2 Digestibility determination

The potential value of a feed for supplying a particular nutrient can be determined by chemical analysis, but the actual value of the feed to the animal can be arrived at only after making allowances for the inevitable losses that are occurred during digestion, absorption and metabolism. Nutrients present in the feedstuffs are not completely available to animal body. Large portion of the nutrients are excreted in the feces because of being not digested in the alimentary tract. Therefore, the digestibility of a feed is most accurately defined as that portion of the feed not exerted in the feces and which is, therefore, assumed to be absorbed by the animals. Digestibility is commonly expressed in terms of coefficient or a percentage basis. Digestibility measures the availability of feed nutrients and provides a very good index of nutritive value of the feed.

6.2.1. Methods of digestibility determination

6.2.1.1. In vivo methods of digestibility test

This is the type of digestibility that takes place within the digestive tract of live animals. This type of digestibility test is assumed to be the most reliable method of measuring the digestibility of a given feedstuff because every activity will take place in animal itself. However, it is more expensive, time consuming and labor demanding activity as more or equal to three animals per treatments are required as well as time needed for adaptation of animals to the feed and consequent time required for intake and feces determination period and also labor needed to manage the animals under trial. With simple theoretical assumption the digestibility determined in this method is the difference between dry matter of feed intake and that of feces. In this method the feed under investigation should be given to the animals in a quantified amount and the amount of feces voided should be correctly recorded. Moreover, the nutrient composition of the feed and feces are need to known to estimate digestibility. Generally, the feed under trial is expected to be thoroughly mixed before provision and adapted at least for a week before start of actual intake and feces determination to accustom the animals to the feed and to clear the residue of the pervious feeds from the tract. For this purpose at least three animals must be used for a single digestion trial of the same species, age and sex and commonly of male animals. Animals under this are expected to be have good health and relatively docile. In the digestion trial it is highly desirable that feeds should be given at the same time each day and the amount of feed eaten should not vary from day to day. When intake is irregular there is a possibility leading to unreliable intake and fecal output. In this method the value generated is called apparent digestibility rather than true digestibility as some endogenous components are excreted in feces in addition to feed fecal output.

$$\text{Apparent digestibility (\%)} = \frac{[\text{Nutrient in feed} - \text{nutrient in feces}]}{\text{Nutrient in feed}} \times 100$$

$$\text{True digestibility (\%)} = \frac{\text{Nutrient in feed} - [\text{nutrients in feces} - \text{metabolic fecal loss}]}{\text{Nutrients in feed}} \times 100$$

Example. A cow consumes 10 kg of hay which has 90% DM and excreted 30% of DM in the feces. What is the digestibility of the hay DM?

$$\% \text{ Digestibility} = \frac{\text{DM in feed} - \text{DM in feces}}{\text{DM in feed}} \times 100$$

$$\text{DM in feed}$$

$$= \frac{(9 - 3)}{9} \times 100$$

$$9$$

$$= 66.6\%$$

6.2.1.2. In vitro methods of digestibility test

Since conventional method of digestibility trial is laborious to undertake and expensive, there have been numerous attempts made to determine the digestibility of a feed by simulating in the laboratory the reactions which take place in the alimentary tract of the animal. This involves the combination of chemical system with rumen fluid which is faster and often gives better replication but give a poorer reflection of biological reality. It is commonly applicable for ruminant than for non-ruminants as it is difficult to simulate the environment that is relatively similar to digestive tract. As a result in ruminant animals digestive tract secretions are collected through canola and to use them to digest feeds *in vitro*. As a result it is possible to quantify digestibility of feed for ruminants with quite better value in the laboratory by treating them first with rumen liquor and then with pepsin. With this method apparent or true digestibility can be estimated. For this method Tilley and Terry (1963) developed the two stages method consisting of 48 hours incubation with the rumen fluid followed by another 48 hours with a proteolytic enzyme (pepsin). The rumen liquor used in the first stage of laboratory procedure may vary in its fermentative characteristics according to the diet of the animal from which it is obtained. In the second stage the rumen bacteria are killed by acidifying with hydrochloric acid and then digested by incubating them with pepsin for 48 hours. Dry matter disappearance is determined by subsequent filtration, drying and weighing of the residues.

The modified Tilley and Terry system (Van Soest *et al.*, 1985) substitutes the second stage (pepsin digestion) with a neutral-detergent extraction. This treatment removes all indigestible microbial matter and leaves a residue of undigested plant cell wall. The values are estimates of true digestibility; apparent digestibility must be estimated by subtraction of the metabolic dry matter extraction value of 12.9. This method is as the original procedure and requires half the time to complete.

Digestibility determined *in vitro* is generally slightly lower than that determined *in vivo*, and corrective equations are required to relate one measure to the other. In all conditions where *in vitro* digestibility will take place should be in test tube under anaerobic conditions. *In vitro* test can estimate the digestibility of the feed within 1-3% of conventional determined value. However, it more predictor of digestibility than predictive equations using chemical composition since it accounts for a factors affecting digestibility and in part as it use of rumen fluid from donor animals. It is also provides very quick and cost effective value provided that laboratory materials are sufficiently available. Addition of buffer solution to rumen fluid is important to buffer the acid produced during fermentation. Commonly used sample to inoculum buffer ration is 0.5 g:8 ml rumen fluid: 32 ml McDougall's buffer. In the process running blank value is needed to account for the indigestible material introduced into the vessel by the rumen fluid, which should not be counted against the feed. The blank value is determined by incubating rumen fluid and buffer alone.

$$\text{In vitro DM digestibility} = \frac{[\text{initial dry sample weight} - (\text{residual weight} - \text{blank weight})]}{\text{Initial dry sample weight}} \times 100$$

Initial dry sample weight

➡ **Factors that influence the accuracy of in vitro method**

- ❖ Variation in the microbial population: this is brought by the diet of the donor animals, animal to animal difference, inoculum processing
- ❖ Variation due to different storage, grinding and processing techniques in sample preparation
- ❖ Differences attributed to the fermentation medium such as sample to inoculum ratio, buffer solution and nutrients in the medium
- ❖ Procedural variation such as length of fermentation and laboratory error

6.2.1. 3. In sacco digestibility technique

The system is also called in situ, nylon bag, cloth bag methods. The nylon-bag technique provides a means of *ranking feeds* according to the *rate* and *extent* of degradation of dry matter, organic matter, nitrogen or other nutritional parameters. It involves incubating samples of feeds in the rumens of fistulated animals for periods from 6 to 120 hours and subsequent determination of the disappearance of the different feed components. The disappearance of the feed from the bag is an

estimate of degradability. It uses a bag with 6.5cmx14 cm made of nylon mesh/pore size of 30-50µm. The pore size of the bags must allow entry of rumen microbes and escape of accumulated gases, and keep solid particle losses to a minimum. The *efflux* of feed particles from the bags without breakdown by rumen microbes is corrected by using zero-hour bags. These bags are filled with the substrate but are not incubated in the rumen; they are washed and dried in the same way as the incubated bags. Furthermore, the zero-hour bags are used to correct for passage of material from pressure applied to the nylon bags during washing.

The nylon-bag technique is a very simple and useful biological tool for *in sacro* animal nutrition studies. If determination of the dry-matter disappearance is the only analysis of importance, then the main analytical equipment needed would be accurate balances and drying ovens. In general, the following materials are required to determine the degradability of feeds using the nylon-bag method:

The nylon-bag procedure

The following procedure can be commonly undertaken during degradability test:

-  Grind the feeds through a 2 mm screen (mesh).
-  Dry the ground samples in an oven at 100–105 °C overnight to determine the dry matter (DM).
-  Number 6.5 x 14 cm nylon bags with a pore size of 30-50µm, oven dry at 60–65°C for 30 minutes and measure their empty weights immediately, or after allowing cooling to room temperature in desiccators. The ratio of width to length of the bags should be between 1:1 (i.e. square) and 1:2.5.
-  Place about 2.0 g DM of sample in each nylon bag. Sample size should be related to the total surface area of the bag; although there is no consensus 15 mg of sample material per square centimeter of bag (bag area includes all the external surfaces) has been suggested.
-  Tie the bags tightly using nylon string which is resistant to rumen micro-organisms.
-  Place the bags deep into the rumen of a fistulated animal.

Incubation

Incubate samples for 0, 6, 12, 24, 48, 72, 96 and 120 hours for forages and up to 48–72 hours for concentrates. Place the 120-hour samples into the rumen on the

morning of day 1 of incubation in each fistulated animal. On the next morning (day 2), insert the 96-hour samples at the same hour as the day 1 samples. Continue the activity in the same manner until all samples are in the rumen.

The samples, which are mostly prepared in triplicate for every feed and each incubation hour, are incubated in each of the experimental animals in the same way. For cattle, 40 to 60 bags can be incubated at the same time while for sheep/goats 8 to 10 bags can be used for each animal. The alternative method is to incubate all the bags on day 1 at the same time and withdraw them at different times (sequential withdrawal). The advantage of sequential addition over sequential withdrawal is that there is less disturbance of the rumen environment.

Washing and drying

Immediately wash the bags (including the zero hour samples) with cold water for about 30 minutes in a washing machine or under running tap water while rubbing gently between thumb and fingers until the water runs clear. Dry the washed bags in an oven at 60–65°C for about 48 hours. Either allow them to cool down in a desiccator or weigh immediately. Determine the dry matter of the residue samples using the same method as with feed samples. Finally, calculate the disappearance using the formula:

$$\text{Disappearance} = \frac{(\text{SWa} - \text{BW}) \times \text{DMa} - (\text{SWb} - \text{BW}) \times \text{DMb}}{(\text{SWa} - \text{BW}) \times \text{DMa}}$$

where: SWa = Weight of the original sample + nylon bag

BW = Weight of empty nylon bag

SWb = Weight of the sample + nylon bag after incubation

DMa = Dry matter of feed sample

DMb = Dry matter of residue sample.

Results of nylon bag degradability are influenced by:

- **How the bags are placed in the rumen:** in general the bag is placed in the lower part of the rumen (in the ventral sac of the digestive tract. The periodic movement of the gastric move up and down the sacc inside the rumen.

- **Particle size of the sample vis-à-vis the pore size of the bags:** large particle size and small pore size will affect the degradability.
- **Loss of feed particle through the nylon bag cloth** (a function of fineness of grinding, cloth pore size and feed material)
- **The methods of washing the residues** (hand washing vis-à-vis machine washing)
- **The length of rumen incubation period for which the feed is incubated in the rumen**
- **The rumen environment:** availability of the necessary substrate for the microbial activities. Types of feed and feeding rate can affect rumen environment.

6.2.1.4. Indicator method

Apparent digestibility of a diet can be estimated using a natural constituent of the feed as an indicator. This is achieved through use of indigestible components that are completely indigestible by the gut. These substances are called indicators. This type of measurement is used in cases where it is impractical to do conventional digestibility trial such as when animals are **fed in group** or **for grazing animals**. The assumption behind use of indicators in digestibility test is that all the consumed indicators are expected to be excreted. Generally, markers are categorized into two: **internal indicators** (lignin, acid insoluble ash, long chain hydrocarbons of C33-35 and indigestible ADF) and **external indicators** (indigestible substrates added to the feed such as chromium oxide (Cr_2O_3), cerium, dysprosium and ytterbium). If the concentration of the indicator in the feed and the sample of faeces are known, digestibility can easily be calculated. The ratio between the concentrations of indicators in the feed and the concentration of indicators in the faeces gives an estimate of digestibility.

To be used as ideal indicators the markers are expected to fulfill the following:

- Should be inert, with no toxic physiological effect on the animal and microbes
- Should not be absorbed or metabolized within the gut
- Should be intimately associated to the material it is to mark
- Should not influence gut secretions, digestion, absorption and motility

Should have physiochemical properties which allow precise qualitative analysis and must not interfere with other analysis

Sampling

Collect samples of every feed used in the experiment and analyse for marker or indicators. During the last six days of each collection period or experiment collect faecal grab samples at five representative times a day. The precise timing is determined by the individual trials. Pool samples for each animal and period and freeze them. The samples are subsequently thawed, dried at 60°C and stored at room temperature for later analyses. This procedure stops the faeces growing mould.

Digestibility of dietary constituents can be calculated after chemical analyses as:

$$\% \text{ Digestibility} = \frac{\% \text{ indicator in the feces} - \% \text{ indicator in the feed}}{\% \text{ indicator in the feces}} \times 100$$

Factors affecting digestibility

➡ Common factors that affect digestibility of feedstuff

- ⊕ **Feed composition:** The digestibility of the feed is closely associated with its chemical composition.
- ⊕ **Ration composition:** The digestibility of a feed is influenced not only by its own composition but also by the composition of other feeds consumed with it.
- ⊕ **Preparation of feeds:** The different treatment methods used in feed processing have their respective effect on feed digestibility.
- ⊕ **Enzyme supplementation of the feed:**
In non-ruminant animals' supplementation of specific enzyme greatly increased digestibility and nutrient availability.
- ⊕ **Animal factors:** Digestibility is more a property of the feed than of the consumers, but this in not to mean a feed given to different animals will also be digested to the same extent. The most important animal factor is the species of the consumers.
- ⊕ **Level of feeding:** An increase in the quantity of feed by the animal generally causes a faster of passage of digesta. The feed is then exposed to

the action of digestive enzymes for a shorter period, and there may be a reduction in its digestibility.

6.3.1. Determination of Energy Value of Feeds

An animal deprived of feed continues to require for those functions of the body immediately necessary for life: for the mechanical work of essential muscular activity, for chemical work such as the movement of dissolved substances against concentration gradients, and for the synthesis of expanded body constituents such as enzymes and hormones. In starved animals, such above mentioned demand of energy is obtained by the catabolism of the body's reserves, first of glycogen, then of fat and protein. However, in fed animal the primary demand of energy of feed is in meeting the requirement for body maintenance and so preventing the catabolism of the animal's tissues. The amount of energy that a feed will supply to an animal can be estimated by measuring the amount of energy that is produced when the feed is completely burnt. This gives the Gross Energy (GE) content of the feed, measured in MJ or kilocalories. However, it is only of limited use since all feeds (apart from those with a very high fat or oil content) have about the same gross energy content. Some other means of evaluating energy values is clearly needed, since straw obviously has lower energy content than maize grain, but the two have very similar gross energy contents.

✚ Basic terms related with energy expression:

Calorie: is the amount of heat required to raise the temperature of one gram of water to by one degree centigrade (1°C) from 14.4 to 15.5 degree centigrade.

Gross energy (GE): is the amount of heat, measured in calories, that is released when a substance is completely oxidized in bomb calorimeter containing 25 to 30 atmospheres of oxygen. Heat of combustion is similarly used term for the above.

Metabolic body size ($W_{\text{kg}}^{0.75}$): is the weight of the animal (in kg) raised to the three-fourths power.

Gross energy feed intake (GEi): the gross energy of the feed consumed. It is estimated as dry weight of the feed consumed times GE of feed per unit of dry weight.

Fecal energy (FE): is the gross energy of the feces. It consists of energy content of the undigested feed and of the metabolic (body) fraction of the feces. $FE = \text{dry weight of the feces} \times \text{GE of the feces per unit of dry weight}$.

Apparent Digestible Energy (DE): It is the difference of GE_i and FE.

Gaseous Products of Digestion (GPD): is the combustible gases produced in the digestive tract by the fermentation of the ration. The energy of these gases (methane) can be estimated from the gross energy of the diet. Methane makes up the largest portion of the combustible gases produced. Ruminants produce most methane; however, nonruminants also produce methane.

Urinary Energy (UE): is the gross energy of the urine. It includes the energy content of the nonoxidized portion of the absorbed nutrients and the energy contained in the endogenous (body) fraction of the urine.

Metabolizable Energy (ME): $ME = GE_i - FE - GPD - UE$

Nitrogen Balance (NB): is the nitrogen in the feed intake (NI), minus the nitrogen in the feces (FN), minus nitrogen in the urine (UN); $NB = NI - FN - UN$. The nitrogen balance must be calculated to account for the nitrogen retained in or lost from the body tissues and to adjust the ME accordingly. For precise work, the nitrogen lost by perspiration and other epidermal excretions should be taken into account. For some types of research, the nitrogen in the products synthesized, such as milk, egg or wool should be considered.

Nitrogen-corrected Metabolizable Energy (ME_N): it is the total ME as corrected for nitrogen retained or lost from the body

Heat of Fermentation Corrected Metabolizable Energy (ME_{hf}): is the growth energy of feed intake minus fecal energy, gaseous products of digestion, heat of fermentation and urinary energy. $ME_{hf} = GE_i - FE - GPD - HF - UE$

Heat Increment (HI): is the increase in heat production following consumption of feed when the animal is in a thermally neutral environment. It consists of increased heats of fermentation and of nutrient metabolism.

Heat of fermentation (HF): is the heat produced in the digestive tract as a result of microbial action.

Heat of Nutrient Metabolism (HNM): is the heat produced in intermediary metabolism as a result of using absorbed nutrients.

Net Energy (NE): It is the difference between ME and HI. It includes the amount of energy used either for maintenance only or for maintenance plus production. Below the critical temperature some of the HI is also part of net energy. When reporting NE, one must state clearly which functions are included

Net Energy for Maintenance (NE_m): is the fraction of total NE expended to keep the animal in energy equilibrium. In this state, there is no net gain or loss of energy in the tissues.

Net Energy for Production (NE_p): is the fraction of net energy required (in addition to that needed for body maintenance) for involuntary work, for tissue gain (growth or fat production), or for the synthesis of a fetus, milk, eggs, wool, fur, feathers etc. It should always be clearly stated which production functions are included.

Energy Balance (EB): is the relation between the GEi and the energy output. It is calculated as **EB**= GEi-FE-UE-GPD-HP.



Gross Energy of the feed

Animal obtain energy from its feed. The quantity of chemical energy present in a feed is measured by converting it into heat energy, and determining the heat produced. This conversion is carried out by oxidizing the feed by burning it; the quantity of heat resulting from the complete oxidation of unit weight of a feed is known as the gross energy or heat of combustion of that feed.

Gross energy is measured in an apparatus known as bomb calorimeter, which in its simplest form consists of a strong metal chamber (the bomb) resting in an insulated tank of water. The feed sample is placed in the bomb, and oxygen admitted under pressure. The temperature of the water is taken, and the sample is then ignited electrically. The heat produced by the oxidation is absorbed by the bomb and the surrounding water, and when equilibrium is reached the temperature of the water is taken again. The quantity of heat produced is then calculated from the rise in temperature and the weights and the specific heats of the water and the bomb.

The bomb calorimeter can be used to determine the gross energy content of whole feeds or their constituents, and of animal tissues and excretory products. The primary determinant of the gross energy content of an organic substance is its degree of oxidation, as expressed in the ratio of carbon plus hydrogen to oxygen.

Digestible Energy Content (DE)

A more useful measure of the energy value of feeds is the estimate of digestible energy content. This takes account of the amount of energy that is lost in the feces, having not been digested and absorbed by the animal.

Metabolizable energy

Animals suffers a further losses of energy-containing substances in its urine, and particularly if it is a ruminant, in the combustible gases leaving the digestive tract. The metaboizable energy of the digestible energy is less than the energy lost in urine and combustible gases. The energy of urine is present in nitrogen containing substances such as urea, hippuric acid, creatinine and allantoin and also in such non-nitrogenous compounds as glucuronates and citric acid.

Metabolizable energy value of a feed is determined in a feeding trial similar to a digestibility trial, but in which urine and methane, as well as faeces are collected.

The energy in the feed, minus that lost in the feces, urine and as methane, is known as the metabolizable energy (ME), and is the term usually used to assess the energy value of ruminant feeds.

Net energy

The deduction of heat increment of a feed from its metabolizable energy gives the net energy value of the feed. The net energy of a feed is that energy which is available to the animal for useful purposes such as for body maintenance and for the various forms of production. Net energy used for maintenance is mainly used to perform work within the body and will leave the animal as heat. That used for growth and fattening and for milk, egg or wool production is either stored in the body or leaves it as chemical energy and the quantity so used is referred to as the animal's energy retention. It is important to understand that of the heat lost by the animal only a part, the heat increment of the feed, is truly waste energy which can be regarded as a direct tax on the feed energy. The heat resulting from the energy

used for body maintenance is considered to represent energy which has been used by the animal and degraded into a useless form during the process of utilization.

6.3. 2. Determination of Protein value of Feed

While the estimation of crude protein content will give a reasonable estimate of the Amount of protein in a feed, of perhaps greater importance is the quality of that protein. The very different digestive systems of pigs and poultry compared with sheep and goats mean that the assessment of protein quality differs for these two classes of animal.

Degradable Protein

When a sheep or goat eats any protein, it first goes into the rumen, where it is attacked by the rumen micro-organisms. How much of the protein gets degraded by the micro-organisms depends on how fast the protein is broken down by them, and on how fast feed leaves the rumen. If the feed is broken down quickly, and feed flows out of the rumen only slowly, then most if not all of the protein will be broken down (degraded) in the rumen. If the feed is broken down slowly, and feed flows out of the rumen more quickly, then little if any of the protein will be degraded. Degraded protein will only be of any use to the animal if the rumen micro-organisms are able to build it up into microbial protein. This microbial protein will then eventually leave the rumen and be digested, absorbed and used by the animal. The rumen micro-organisms will only be able to use degraded protein to make microbial protein if they have enough energy. They will get this energy from fibre (if it can be degraded), but also from sugars and starch in the diet. They will not get any energy from fat or oil in the diet, as micro-organisms are unable to ferment fat to any great extent.

Estimation of Degradable Protein

The common way to estimate how much and how quickly a protein will degrade in the rumen are to take samples of the feed and put them in porous bags. These are placed in the rumen of an animal (usually sheep, cow or buffalo) that has been operated on so that it has a hole (with a cap on it) in its rumen. The bags are taken out at different times, and the amount of protein that is left in the feed that is still left in the bag is measured. From the amount of protein that is left in the bag at different times, the rate (and extent) of protein degradation can be calculated.

Protein degradability is usually expressed using three terms, *a*, *b* and *c*. *a* is the proportion of protein that is almost immediately degraded, and so is likely to be degraded in the rumen no matter what the outflow rate is. *b* is the proportion of protein that is *potentially* degraded, depending on the relative rates of degradation and outflow. *c* is the rate of degradation of *b*.

To calculate the proportion of protein that will be degraded, you also need to know the outflow rate from the rumen (*k*). For most tropical livestock, being kept at or near maintenance, this is likely to be 0.02/h. In other words, 2% of the material in the rumen will flow out into the animal's lower gut every hour. The proportion of a feed's protein that is degradable can be calculated from the equation:

$$\text{Degradability} = a + bc / c + k \quad \text{and since usually } k = 0.02 \text{ then Degradability} = a + bc / c + 0.02$$

Digestible Undegraded Protein

The protein that is not degraded in the rumen may be digested and absorbed by the animal. This protein is called digestible, undegraded protein (DUP). There are times (particularly in early lactation) when animals may need some DUP to meet all their needs for protein, if the rumen micro-organisms are not able to make enough protein for the animal. To estimate how much undegraded protein is supplied by a feed, subtract the degradable protein content away from the feed's crude protein content:

$$\text{Undegraded protein} = \text{Crude protein} - \text{Degradable protein}.$$

Not all of this undegraded protein will be digested by the animal. With most feeds, however, 95-98% of the undegraded protein will be digested by the animal and if there is no other information available then this is probably a reasonable estimate to use. To estimate the amount of *indigestible* protein there is in a feed, a feed might be heated with acid detergent, and the nitrogen content of the residue determined. This gives an estimate of the feed's acid detergent insoluble nitrogen (ADIN) content, and is taken to be an estimate of the N fraction that will not be digested in the gut. To estimate the indigestible protein content, therefore, the ADIN content is multiplied by 6.25 (see estimation of crude protein for an explanation). **Indigestible protein (IP) = ADIN x 6.25.** The digestible,

undegraded protein content of the feed may then be calculated from: **DUP content**
= CP content - Degradable protein content - IP