Part 01 : Physiology of digestion

Digestion of food

Digestion is the transformation of food into molecules capable of passing from the lumen of the digestive tract into the internal environment. It includes:

- Reduction of the'food molecules=*digestion*(after ingestion)
- Passage from the middle east to the inner middle=*absorption*
- Recovery of molecules by cells of the'body=*assimilation*

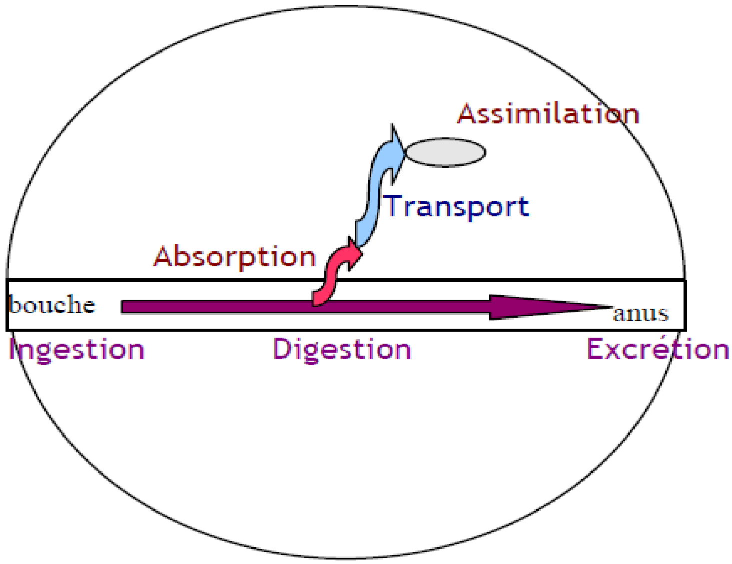

Fig.1: Phases of digestion

- In polygastric ruminants, the particular configuration of their digestive tract allows for microbial predigestion of ingested food, facilitating extensive use of the fibers present in the ration.
- The rumen is an ecosystem populated by microorganisms that live in symbiosis with the ruminant.

  These microorganisms, adapted to living in an environment characterized by a pH of 6.0 to 7.0, degrade, via processes of hydrolysis and fermentation, most of the components of the food ration.

Transformation of food into nutrients

The main objective of digestion is the transformation of ingested food (complex) into products of simpler composition: the nutrients will be absorbed by the digestive mucous membranes.

This degradation takes place at the level of the different segments of the digestive tract; it is carried out by processes:

- Mechanical: grinding, softening, mixing.
- Chemical: under the action of enzymes.
- Biological: under the action of microbial fermentations.

1- Digestion in the rumen-network

➲ **Biological degradation of food**

- One of the characteristics of digestion in ruminants is the participation of microorganisms living in the rumen in digestion. The rumen and the network form a vast fermentation tank where food is put to:
    - mechanical actions.
    - Microbial actions (biological or fermentative digestion).
- This fermentative digestion is obligatory and very effective because it conditions the digestibility of carbohydrates and proteins.

➲ **Rumen network movements**

- Swallowed food falls into the rumen network, it first floats above the liquid and then sinks into its cavity, mixing with the ingesta. It undergoes softening thanks to the contractions of the reticulorumen musculature.
- Although each of the forestomachs is endowed with automatism and can contract independently of the other, the rumen and the network are in close synchronicity in their movements.
- Gastric cycles:
    - *Primary cycle*(the simple cycle): it is a permanent cycle that is renewed every minute, its duration is 10 to 20 seconds. It begins with a jerky biphasic contraction of the network, followed by two contractions of the rumen (contraction of the dorsal sac then of the anterior ventral sac). This cycle of contractions aims to push the digesta from the network towards the rumen in order to subject them to a new mixing.

- *Secondary cycle*: it occurs immediately following the simple cycle. The latter is manifested by a contraction that begins at the level of the posterior ventral sac and spreads towards the anterior dorsal sac then ends at the level of the anterior ventral sac. The presence of this contraction corresponds to the belching of gas.

  The frequency of secondary cycles relative to the primary cycle varies depending on gas production. The motor movements of the forestomach are under the control of the nervous system (the pneumogastric nerve). They are determined by reflexes whose origin is mainly in the rumen and the reticulum.

Rumination

In ruminants, mechanical digestion begins with vigorous grinding:

- The first chewing is rapid, 70 to 90 movements per minute. The poorly divided food is piled up in the rumen with drinking water and saliva.
- The rumen is chewed in the mouth, followed by a second chew and a second salivation before returning to the rumen. Despite some similarities, this is a different phenomenon from vomiting; vomiting is a violent and pathological act, while rumination is a slow, calm and physiological act.

➲ ***Stages of rumination***

❶*Regurgitation of food bolus*

The mechanism of rumination is very complex. Regurgitation takes place in two phases:

⇨*Suction phase*

At the beginning of rumination, the animal takes a deep breath. This inspiration creates an intrathoracic depression (which corresponds to a relative vacuum of the esophagus) and an increase in intra-abdominal pressure. This pressure difference causes rapid aspiration of the rumen contents through the relaxed cardia.

⇨Expulsion phase:

During this phase, the rumen bolus will be transported to the mouth by an esophageal contraction. An isolated contraction of the network would have the effect of forcing more solid particles of the rumen contents into the esophagus.

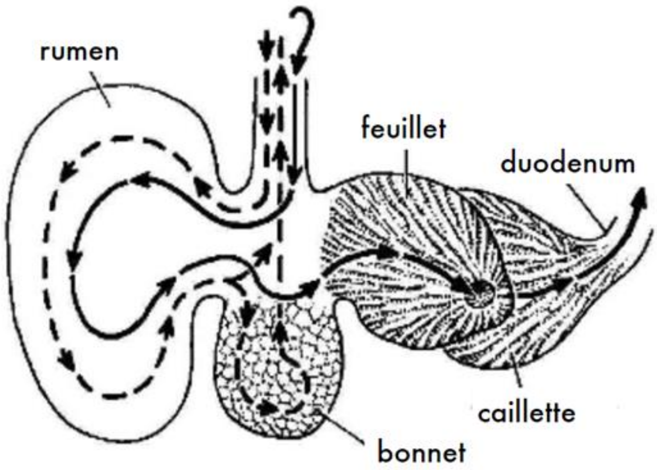

Fig. 2: Stages of rumination

❷*Mericic chewing*

The chewing of regurgitated products is intense and careful, its rhythm is slower than the first chewing, with an average of 55 movements/minute and lasting about one minute.

❸*Mericic swallowing*

The very watery rumen is squeezed into the mouth, and the expressed juice is then swallowed, that is, it immediately returns to the stomach. Shortly after swallowing, a new cycle of rumination begins.

➲ Periods of rumination

Rumination periods vary greatly in duration; in beef, they occur 8-10 times/day and 4-6 times/day in small ruminants, spread throughout the day. Each period can last 40-50 minutes and the time spent ruminating is on average 10 hours. This varies with the composition and volume of the ration:

- The higher the proportion of fiber-rich forage, the longer the time required for rumination;
- With a concentrate-based diet, the rumination time is very short, around 30 minutes.

➲ ***Interest of rumination***

Rumination occupies an important place in the life of ruminants, it allows:

➯ Of carefully fragment the contents of the rumen, which are still quite coarse, by breaking the cell membranes and causing intense secretion of saliva;

➯ To increase the surface area of the food content which is favorable to the action of microorganisms.

➩ To accelerate its transit towards the leaflet because the passage of the ingesta in the leaflet and the

Caillette can only be made if the food is sufficiently crumbled.

➲ ***Rumination is subject to certain conditions***:

➩ The rumen must be sufficiently full;

➩ The ration must contain coarse foods which act by their roughness on the alveoli of the Network ;

➩ food must be in a sufficiently liquid medium;

➩ Rumination usually takes place during rest, the animal is lying down for 80% of the rumination time;

➩ it is inhibited by poor health: fever, bloating, pain.

The ruminal environment

- The rumen is a strictly anaerobic ecosystem where most of the components of lignocellulosic feed are broken down and fermented by an extremely abundant and diverse microflora and microfauna. Microorganisms and ruminants thus live in a mutually beneficial association called symbiosis. Thus, feeding the cow means, above all, feeding the microbial flora of its rumen.
- The microbial population is made up mainly of bacteria, protozoa and fungi, representing a few billion per millilitre of rumen juice which weighs a total of 2 kg of dry matter.
- These microbial populations are adapted to live at pH values between 5.5 and 7.0, in the absence of oxygen, and at a temperature of 39-40°C.
- The essential function of rumen microorganisms lies in their ability to degrade and ferment polysaccharides from plant walls into compounds that can be assimilated by the host that accommodates them. These fermentations involve:
    - hydrolytic populations hydrolyzing parietal polymers,
    - populations fermenting soluble carbohydrates that come from food or from the degradation of parietal polymers by the first group,
    - populations that use organic acids (succinic, formic, lactic) produced by the preceding species,

  - methanogenic species that use hydrogen and formic acid produced by other species to form methane.
- In the case of nitrogen, the sequential activity of the proteolytic, peptidolytic and deaminating populations leads to the production of ammonia.
- A second activity, less well known but nevertheless important, lies in the ability of microbial populations to metabolize and detoxify certain harmful components naturally present in plants (oxalic acid, mimosine, ochratoxin, etc.), thus exercising a very effective protective function with respect to the host.

➲ *Bacteria*

- Bacteria represent the main component of the rumen microbial population (half of the microbial biomass). About forty genera and more than sixty species have been described.
- The rumen contains 20 to 40x108 bacteria per ml of rumen juice, or approximately 1 kg of bacteria in a cow (which corresponds to 10% of the dry matter of the reticulo-rumen).
- They ensure the digestion of plant walls, protein and vitamin synthesis.

  ➢ *Cellulolytic and hemicellulolytic bacteria*

– represent more than 25% of the bacterial population (fibrobacteria and ruminococcus);
– Produce cellulase, well developed with high forage diets;
– can also use cellobiose;
– Very sensitive to acid pH (need for pH > 6);
– Use nitrogen in the form of ammonia (NH_3);
– Require sulfur for the synthesis of sulfur amino acids (cysteine and methionine);
– Produce acetate, propionate, some butyrate and CO_2;

  ➢ Amylolytic bacteria

– Digest starch(bacteroides, amylophilus);
– Dominant species with high-grain diets;
– Tolerate more acidic pH (pH=5-6);
– Use nitrogen in the form of ammonia (NH_3) or peptides;
– Produce propionate, butyrate and lactates;
– grows explosively when conditions are favorable (lots of starch/sugars and low pH), population doubling takes 13 min.

  ➢ *Proteolytic strains*

Can use amino acids as an energy source: Streptococcus bovis, Bacteroides ruminicola.

- *Lipolytic strains*

Able to use glycerol, triglycerides (which will be hydrogenated): Anaerovibrio lipolytica.

NB/Some bacterial species synthesize B group vitamins in abundance, thus ensuring that the body's needs are met.

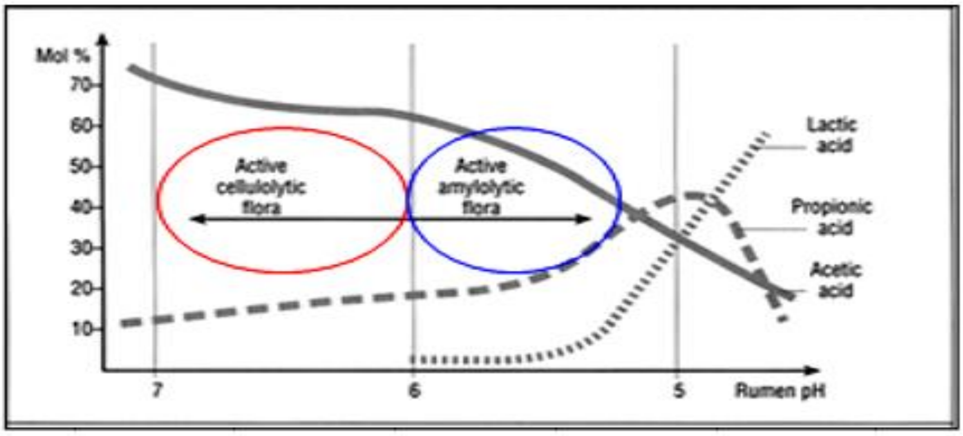

Fig.3: Effect of pH on the orientation of fermentations in the rumen.

➲ *Protozoa*

- Rumen protozoa are unicellular eukaryotic organisms that are ciliated or flagellated;
- represent 40% of the biomass;
- Their concentration can sometimes be significant 104 to 106 /ml;
- are very sensitive to conditions in the rumen, multiply at pH 5.5 – 7.6 with high-energy diets (but rations too rich in concentrate lead to their disappearance by lowering the pH).
- Thanks to their large numbers and very active movements, protozoa participate in the mixing and crumbling of the contents of the rumen.

➲ ***Mushrooms:***

- discovered in 1975, the function of which has not yet been clearly determined; however, they facilitate the work of bacteria and protozoa by participating directly in the digestion of plant walls.
- Their population size is reduced;
- Are able to digest fibers indigestible by other microorganisms (amorphous and highly crystalline cellulose).

Ruminal environmental conditions

- The microbial population living in the rumen requires stable environmental conditions for its development:
  - High temperature: 39-40°C.
  - Anaerobic environment.
  - Neutral pH (6-7).
- pH stability is enabled by:
  - By the role of saliva which is a buffer solution;
  - By ammonia from microbial proteolysis;
  - By the continuous absorption of AGVs through the ruminal mucosa.

2- Digestion in the leaflet

- The leaflet fills through the reticulo-omasal orifice which allows fine particles to penetrate.
- The leaflet does not have digestible secretions; it intervenes through its blades in the crumbling of food.
- Despite its small size, the leaflet has a great absorption capacity; it allows the recycling of water and certain minerals such as sodium and phosphorus which are absorbed into the blood and return to the rumen via saliva.
- Finally, it allows the absorption of AGVs and ammonia.

3- Digestion in the abomasum

- In ruminants, digesta arrives in the abomasum and stays there for a very short time (1/2 hour to 1 hour).
- The functions of the abomasum correspond to those of the stomach of monogastric animals: They have the same composition of gastric juice except that the HCl concentration and the proteolytic activity of the abomasum juice are lower. Its production reaches 100L/day in beef.
- The secretion of gastric juice in the abomasum is continuous because it is maintained by the permanent passage of digesta which extends over more than 1/3 of the day.
- Like the stomach of monogastrics, abomasal contractions are also influenced by the contents of the duodenum (elimination of duodenal contents leads to increased abomasal contractions), but they are slower.

- The pH of the abomasum fluctuates less and is on average lower (2 to 3). These conditions are more favorable to the denaturation of nitrogenous materials and the hydrolysis of proteins under the action of pepsin.
- Microorganisms arriving in the abomasum will be killed by the acidity of the environment. Lysozyme plays an important role in ruminants since it is secreted in abundance, it intervenes in the lysis of bacterial walls (30 to 70% of bacteria and protozoa are detached in the abomasum.
- Microbial proteins undergo enzymatic digestion in the abomasum, leading to the formation of amino acids (AA)
- Absorption would also include unabsorbed VFAs in the leaflet.

4- Digestion ofin the small intestine

- The mechanisms of digestion and absorption in the small intestine are the same as in monogastrics.
- ***Pancreatic juice enzymes*** (trypsins, chymotrypsins A, B, C, elastase, carboxypeptidases A, B, lipase plus colipase, cholesterol esterase, amylase, ribonuclease, deoxyribonuclease) and intestinal mucosa (aminopeptidase A and N, alkaline phosphatase, lactase, maltase and isomaltase) are the same.

➢ *Digestion of carbohydrates*

- starch is hydrolyzed into maltose then into glucose;
- It is estimated that dietary glucose provides on average 5% of absorbed energy. The ruminant must therefore synthesize almost all or most of the glucose it needs from:
    - parietal carbohydrates not degraded in the rumen network and which will not be degraded as well at the level of the small intestine;
    - residues of the bacteria's reserve polysaccharides.

- **Carbohydrates or carbohydrates** is divided into three main groups:
    - **Polysaccharides**: Starch, cellulose
    - **Disaccharides**: lactose, maltose, sucrose
    - **Monosaccharides**: glucose, galactose, fructose .
- **Carbohydrate-specific enzymes**
    - **Pancreatic amylase**: acts on starch and produces maltose
    - **Maltese**: acts on maltose and produces two glucose molecules (small intestine)

- **Sucrase**: acts on sucrose and produces a glucose molecule and a fructose molecule (small intestine)
- **Lactase**: acts on lactose and produces a glucose molecule and a galactose molecule (small intestine)

➢ *Protein digestion*

- The proteins that reach the duodenum are of two types: dietary and microbial.
- It is accepted that 80% of microbial proteins are in the form of true proteins (20% in the form of nucleic acids which would have no value for the animal).
- Protein digestion and absorption would take place mainly in the second third of the small intestine; they would therefore be weak in the ileum despite its high capacities, including a pH of 7.5, which is favorable to the action of proteolytic enzymes.
- The digestibility of proteins in the small intestine varies considerably: from 0.80 for proteins of microbial origin and from 0.25 to 0.95 for dietary proteins.
- **Proteins**are composed of amino acid subunits linked by peptide bonds to form a polypeptide.
- ***Protein-specific enzymes:***
  - **Pepsin**: acts on proteins and produces peptides (stomach)
  - **Trypsin**: acts on peptides and produces simple peptides (pancreas→duodenum)
  - **Carboxypeptidase**: acts on peptides and produces simple peptides (pancreas→small intestine)

➢ *Digestion of lipids*

- Lipids are efficiently digested in the intestine, thanks to bile and pancreatic juice;
- In the duodenum, the supply of lipids by bile leads to a marked increase in the quantities of unsaturated fatty acids, phospholipids and cholesterol (50%).
- Three forms of lipids:
  - Fatty acids
  - Cholesterol
  - Triglycerides
- Enzymes that act on lipids:

- Lipase: acts on triglycerides and produces glycerol and fatty acids (produced in the stomach but active at a lower pH, therefore in the small intestine)
- Pancreatic lipase (produced in the pancreas)

➢ *Digestion in the large intestine*

- The large intestine provides a very favorable environment for microbial digestion.
- The temperature is constant and the pH varies little (6.6 to 7.8);
- The residence time of digesta decreases as the level of ingestion increases, OV:10-29 h
- Cereals decrease cecal activity in ruminants, due to increased or abnormal cecal fermentation;
- The microbial population of the large intestine is not very different from that of the rumen - network but in lower quantities.

➢ *Carbohydrates*

- Only parietal carbohydrates (cellulose and hemicelluloses) not digested in the rumen reach the large intestine, no soluble carbohydrates are detected in the digesta of the ileum (ration based on conventional fodder), may increase with cereal-based rations.
- The microbial population of the cecum and colon utilizes these carbohydrates by producing volatile fatty acids as in the rumen (from 4 to 26% of the total digested energy). The VFAs absorbed at this level represent a very variable fraction.

	Acetic	Propionic	Butyric
Caecum	68.8	18.4	8.7
Colon	72.1	17.2	7.2

- However, the quantities digested there represent:
  - 3.0 to 29.6% for cellulose
  - 7.9 to 41.1% for hemicelluloses digestible quantities throughout the digestive tract.

➢ *Protein digestion*

- 25-50% of the ingested nitrogen reaches the cecum;
- bacteria in the cecum and proximal colon have significant proteolytic activity;
- protein degradation results in the formation of amino acids which are themselves degraded into ammonia, volatile fatty acids and methane;
- The large intestine plays a significant role in the recycling of urea, thus contributing 40% of the net transfer of nitrogen from the entire digestive tract to body fluids.