Part 02 : Food digestion in ruminants

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, through processes of hydrolysis and fermentation, most of the components of the feed ration.

1. Digestion of carbohydrates

Once in the rumen, carbohydrates undergo microbial fermentation leading to the formation of a mixture of volatile fatty acids (VFAs): acetic acid (C2), propionic acid (C3) and butyric acid (C4), the proportions of these 3 fatty acids generally being around 65, 20 and 15. These different VFAs are then absorbed through the rumen wall.

Once in the rumen, carbohydrates are hydrolyzed by microbial hydrolytic enzymes. Glucose is the main end product of this degradation process.
This glucose will then be converted by microbial fermentation into an intermediate metabolite, pyruvic acid. This undergoes further degradation, which will result in the formation of a mixture of VFAs:

- Acetic acid (C2)
- Propionic acid (C3)
- Butyric acid (C4)

*Lactic acid*is an intermediate in this degradation chain. CO_2, CH_4 and heat are also produced during this process.

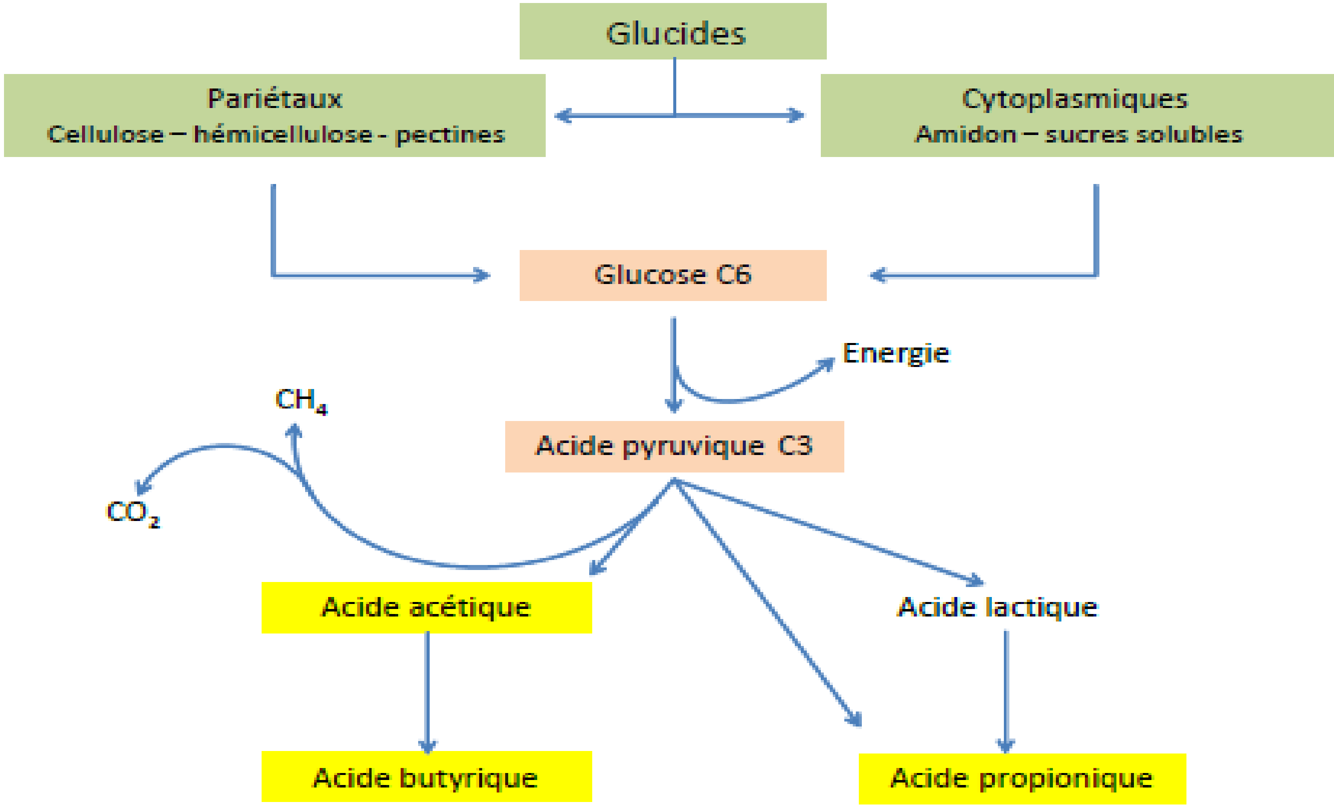


Diagram of carbohydrate digestion in the rumen

1.1. Factors influencing AGV production

Different factors influence the production of VFAs: the nature of the feed ration, the intra-ruminal pH and the animal's ingestion level.

- **The food ration**

- The different carbohydrates (cellulose, hemicellulose, starch, etc.) are degraded by specific bacterial populations:
  - *Cellulose* and hemicellulose are attacked by cellulolytic bacteria;
  - *Starch* is degraded by amylolytic bacteria.
- To do this, each bacterial population uses its own degradation pathways which result in the preferential formation of this or that type of VFA.
- Therefore, the proportions of the different AGVs produced are mainly a function of the composition of the feed ration.
  - Acetic acid is the majority (45 to 70% of total VFAs),
  - propionic acid represents 15 to 25% of total VFAs,
  - butyric acid 5 to 15%.

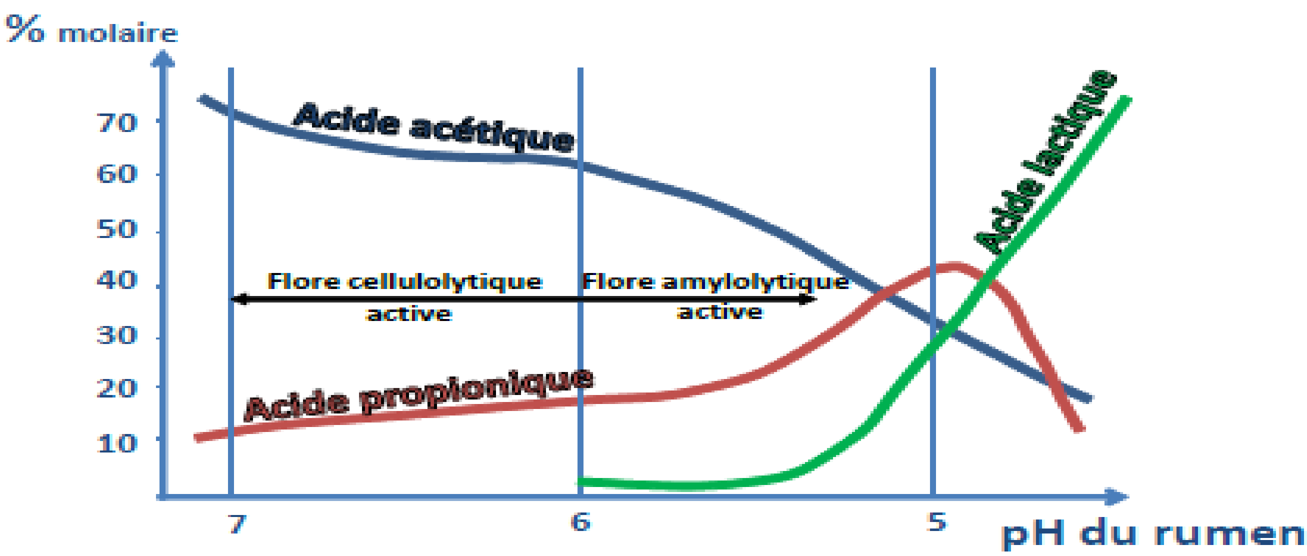
⇨*With a diet rich in forages, the proportions of acetic, propionic and butyric acid are generally respectively 70:20:10.*

⇨*With a diet rich in cereals, the proportion of acetic acid decreases, and that of propionithat increases, the proportions of the 3 fatty acids being rather around 40:40:20.*

⇨*The production of butyric acid is increased when foods rich in sugars solubles, such as beets, are distributed.*

➢ **The pH**

- Intra-ruminal pH is a determining element in the balance between rumen microorganisms and in the resulting fermentations.
- A drop in pH linked to the development of amylolytic bacteria inhibits the activity of cellulolytic bacteria. In doing so, the production of acetic acid decreases and that of propionic acid and lactic acid increases.



Proportions of different A GVs in the rumen as a function of pH

➢ **The level of ingestion**

- The production of VFAs is linked to the quantity of organic matter digested in the rumen: the higher the level of ingestion, the more VFA production increases.
- The various VFAs produced are absorbed through the rumen wall. These VFAs constitute a major source of energy for the ruminant, since they provide 60 to 80% of the total energy it needs for maintenance.

- The gases produced during fermentation, CO_2 and CH_4, are eliminated by belching. The cow expels approximately 300 to 400 g of gas per day, with some dairy cows with high gas intake reaching up to 700 g per day.
- The speed and extent of ruminal digestion of carbohydrates varies according to their nature and botanical origin:
  - Soluble sugars and starch are rapidly fermented.

  ➢ The rate of ruminal digestion of starch varies according to its botanical origin:

    - Starch from oats, barley and wheat, for example, is broken down very quickly, and is therefore quickly made available to microorganisms (fast starch);
    - Conversely, corn, sorghum, and potatoes have starch that is broken down more slowly. This is called "slow starch."

  ➢ The extent of starch degradation in the rumen also depends on the botanical origin:

    - Barley starch is degraded in the rumen at a rate of 90 to 95%,
    - that of corn is degraded in significantly smaller proportions (50 to 90%).
  - *The parietal carbohydrates (cellulose and hemicellulose) are slowly and partially degraded.*(around 30 to 50%). Lignin is not degraded by the ruminant.
- A fraction of the undigested starch in the rumen undergoes enzymatic digestion in the small intestine which results in the formation of glucose, which is absorbed through the wall.
- Undigested starch in the small intestine is partly broken down by microorganisms in the large intestine.
- The parietal carbohydrates that have escaped microbial fermentation can undergo a second fermentation in the colon.

2. *Digestion of lipids*

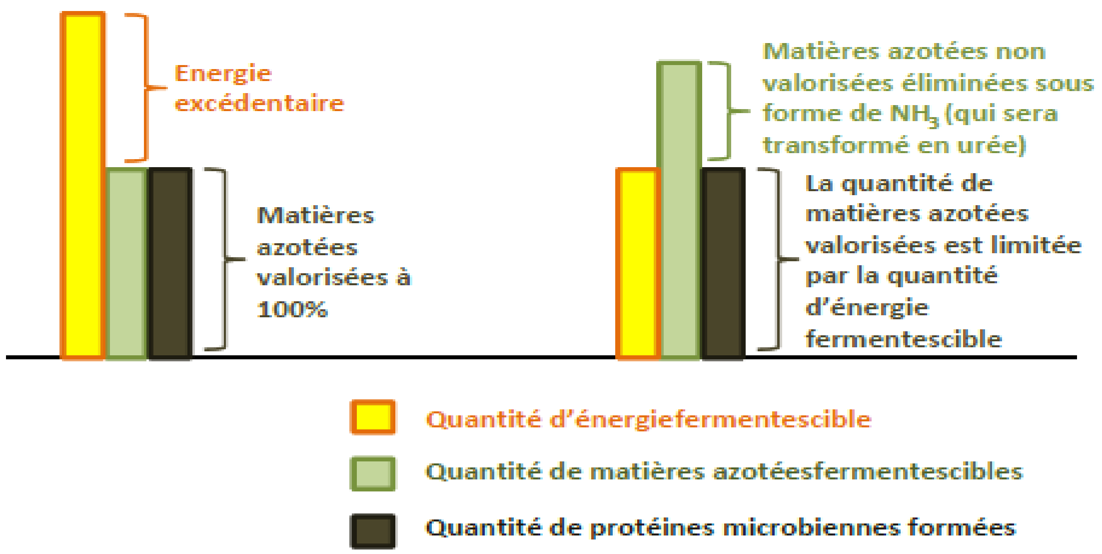
- Ruminant rations generally contain around 3 to 5% lipids in the DM (very little compared to the carbohydrate and nitrogenous matter contents).
- Dietary lipids are hydrolyzed by rumen microorganisms, allowing the production of glycerol and free fatty acids.
- The glycerol formed is rapidly fermented into VFA, while the unsaturated fatty acids are extensively reworked by rumen microorganisms.
- Microorganisms also synthesize microbial lipids within their bodies. These lipids are released when they pass through the abomasum (destruction by gastric juice);

Microbial free fatty acids + dietary free fatty acids⇛intestinal absorption.

3. *Digestion of nitrogenous materials*

- Nitrogenous substancesfood (composed of proteins and non-protein nitrogen) undergo degradation in the rumen±important, includingthe final product is ammonia (NH3):

  Food proteins are thus transformed into AA and then undergo fermentation up to the NH3 stage, while non-protein nitrogen is directly transformed into NH3.
- This ammonia is used by rumen microorganisms to synthesize their own proteins, called microbial proteins.
- This synthesis can, however, only take place in the presence of a sufficient quantity of energy.
- *DTwo elements must therefore be present at the same time for microbial protein synthesis to occur: nitrogenous materials AND energy. If one is present in lower quantities than the other, it will be the limiting factor and will determine the quantity of microbial proteins formed.*



Amounts of microbial proteins formed in the rumen according to the amount of energy and fermentable nitrogenous matter ;

- It is mainly the degradation of carbohydrates via microbial fermentations which will provide the energy necessary for this protein synthesis.
- If there is an excess of nitrogenous matter relative to the energy present, the excess ammonia isabsorbed by the rumen wall, then transformed into urea in the liver.

- This urea is mainly excreted by the kidneys and eliminated through urine and milk in dairy cows. However, it can also return to the rumen via saliva.(phenomenon of recycling of urea through the rumen wall).
- Some of the bacteria attached to food particles leave the rumen and pass into the abomasum, where they undergo enzymatic digestion., leading to the formation of amino acids (AA).
- Part of the proteins in the ration resist ruminal degradation and pass into the abomasum, where they are then degraded enzymatically ("protein bypass").
- Nitrogenous materials in the ration therefore present a great variability in their degradation in the rumen network. The resistance of food proteins to the action of ruminal microorganisms depends precisely on the nature of the protein.
- At the level of the abomasum and the small intestine, all proteins, whether microbial or dietary, undergo the action of digestive enzymes and are degraded into AA.

4. Digestion of minerals

- Macronutrients and trace elements are found in various chemical forms in foods. The form in which they are found determines their absorption in the digestive tract. For example, calcium absorption is limited when it is present in food in the form of calcium oxalates.
- In addition, numerous interactions exist between minerals. Thus, in the small intestine, Ca absorption is positively correlated with inorganic phosphorus concentration, but negatively with magnesium concentration.
- Finally, the absorption of certain elements can also be modulated by the physiological status of the animal in this element: the intestinal absorption of Ca is increased when the calcium concentrations in the blood are low, thanks to the secretion of vitamin D.

5. Food digestibility

- The food ingested by the animal is almost never digested and absorbed completely: some of it ends up in the feces.
- There *apparent digestibility* of a food is the proportion of food that apparently disappears in the digestive tract:

Apparent digestibility= Quantity ingested–amount excreted in feces

- Apparent digestibility is always less than 1. The term*digestibility coefficient* is sometimes used. This is the apparent digestibility multiplied by 100 (expressed as a %):

Digestibility coefficient (%) = Apparent digestibility × 100.

- Apparent digestibility varies depending on the nature of the food, its chemical composition and the possible presence of antinutritional factors.
- In terms of digestibility, we distinguish, for foods:
  - *the constituents of plant cell walls*(cell wall carbohydrates and lignin)
  - *the constituents of cellular content*(cytoplasmic carbohydrates, lipids and proteins).
- Lignin (indigestible), by binding to cellulose and hemicellulose, makes these constituents inaccessible to microorganisms and therefore limits their digestibility.
- The degree of degradation of the walls therefore evolves in the opposite direction to their lignin content: the digestibility of the walls of a young ryegrass is around 90%, whereas that of wheat straw is only 40%.
- The digestibility of foods varies according to the proportions of each constituent:
  - Concentrates, rich in starch, will have high digestibility, as will young fodder, rich in soluble sugars.
  - a fodder for one*vegetation stage*advanced, rich in lignin, will have low digestibility.
- Other factors affect the digestibility of forages:
  - the method of conservation,
  - the composition of the ration,
  - haymaking,
- Silage and dehydration, on the other hand, have little effect on the overall digestibility of feed.
- Forages have relatively long residence times in the rumen, especially if they are presented in the form of long strands. If the forages are ground, the residence time in the rumen is shortened and degradation by fermentation is reduced.
- The decrease in saliva production also promotes a drop in intra-ruminal pH, which leads to a decrease in the activity of cellulolytic bacteria, and therefore a further decrease in digestibility.