



The Ruminant Digestive System

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Introduction

Ruminants are extraordinary animals that evolved from early mammalian ancestors more than 50 to 60 million years ago. The evolutionary success of ruminants as livestock species is largely due to their specialized digestive systems. The particularities of their digestive system give them the ability to use plant-based diets effectively, which allowed them to thrive in a wide range of environments – from arid rangelands to dense forests. Ruminants have developed an endosymbiosis with microbes (when one organism lives inside another in a mutually beneficial relationship), which allows the digestion of plants and to extract nutrients from them. Other particularities that classify those animals as ruminants are the ability to return feed from the stomach to their mouth for more elaborate rechewing (rumination) and the absence of upper canine and incisor teeth.

There are more than 200 species of ruminants divided into six groups inhabiting the planet with different anatomical differences. Among those, common ruminants are cattle, sheep, goats, buffalo and deer. Those species share a relatively similar digestive system anatomy, however with different dietary specializations and behavior. After millions of years of natural selection, the evolution of ruminants has generated three distinct groups related to their feeding behavior: grazers, browsers and intermediate feeders. Essentially, grazers are animals whose diet is formed mainly by grasses. The browser type of ruminants ingests a large proportion of broad-leaf plants in their diet (such as shrubs and trees). They tend to have a selective feeding behavior, often focusing on more nutritious parts of plants. Intermediate feeders can switch between grazing and browsing based on environmental conditions. Cattle, buffalo and sheep are classified as grazers, goats are categorized as intermediate feeders, and deer are considered browsers.

Ruminants are an important component of the food chain, supporting the production of a variety of end products such as meat, milk, leather and wool. However, despite common assumptions, ruminants are not only essential for the meat and dairy industry, but also produce a wide array of products essential to different industry segments, such as pharmaceuticals, nutritional supplements and general biotechnology. Products derived from ruminants used as industrial products are mainly collagen (gelatin), tallow (biofuels, lubricants, soap, etc.), bones (calcium and other supplements), hides and wool (clothing), etc.

Ruminants are indeed fantastic animals with a unique and elaborate digestive system. Their capacity to turn high-fibrous feedstuff into a vital food source for human consumption places them in a critical position within livestock production. This section outlines a brief overview of the digestive system of ruminants, including the anatomy and function of each organ in the gastrointestinal tract.

Anatomy and Function of the Gastrointestinal Tract

The ruminant digestive system can be simply divided into four stomach compartments (reticulum, rumen, omasum and abomasum), small intestine and large intestine (Figure 1). The first three compartments are considered the forestomachs (reticulum, rumen and omasum) and they are the reason these animals are classified as ruminants (Figure 2).

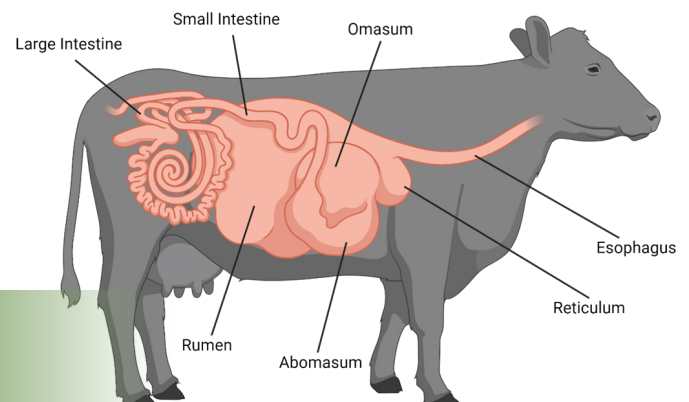


Figure 1. The ruminant digestive system.
Graphic created by authors using BioRender

Rumen and Reticulum

The **Rumen** is the largest organ in the gastrointestinal tract of ruminants, accounting for over 70% of the total digestive tract volume, and perhaps the most important compartment alongside the reticulum. In cattle, volume content in the rumen is 0.3 gallons at birth, approximately 1.8 gallons at 3 months of age, and approximately 16 gallons at maturity. The rumen is essentially a fermentation vat covered with papillae where microbes (bacteria, protozoa and fungi) digest fibrous plant materials into end products called volatile fatty acids (VFAs). Those papillae are involved in the absorption of VFAs produced by microbial activity and are the main source of energy for ruminants. The rumen provides the perfect environment for the proliferation and development of those microbes. It is anaerobic (no oxygen), the ideal temperature (95 F to 107 F) and pH (6.5 to 7.0), and contains water, nutrients and the absorption products of fermentation (Figure 3).

The **reticulum** is a small pouch with honeycomb-like walls connected to the front portion of the rumen. The reticulum collects small digesta particles – or things being digested – and moves them into the omasum, while the larger particles remain in the rumen for further digestion. The reticulum is also responsible for trapping and collecting heavy or dense objects that the animal ingests. If a ruminant consumes a sharp, heavy item like a nail or wire, it is likely to become lodged in the reticulum. The reticulum works closely with the rumen in the fermentation process and acts to facilitate the process of rumination. Together, rumen and reticulum form one large, integrated sac known as the **reticulorumen** occupying most of the left side of the abdominal cavity. Internal pillars, commonly known as grooves, separate the reticulum from the rumen, and although the groove that separates both is prominent, the opening between the reticulum and rumen is large, which allows digesta to move between those compartments (Figure 3).

Omasum

The omasum is a spherical compartment located on the right side of the abdominal cavity connected to the reticulorumen by a short and narrow tunnel called reticulum-omasal orifice. It has more than 150 thin longitudinal folds that resemble pages in a book (also called “many piles” or the “butcher’s bible” in reference to that). Those parallel folds or sheets contain small papillae that give the omasum an absorptive surface area (Figure 4). The main function of the omasum is to absorb water, electrolytes and VFAs that were not absorbed in the rumen, as well as decrease the particle size of feeds before passing to the abomasum.

Abomasum

The abomasum is considered to be “true stomach” and corresponds to the stomach of monogastric animals, or in other words, simple stomach animals (pigs, dogs, chickens, etc.). Different from the forestomachs, the abomasum has the capability of producing and secreting enzymes for digestion or gastric juices (hydrochloric acid and digestive enzymes) that break down proteins and other nutrients (Figure 5 on page 3). The abomasum prepares the digesta for further digestion and absorption in the small intestine.

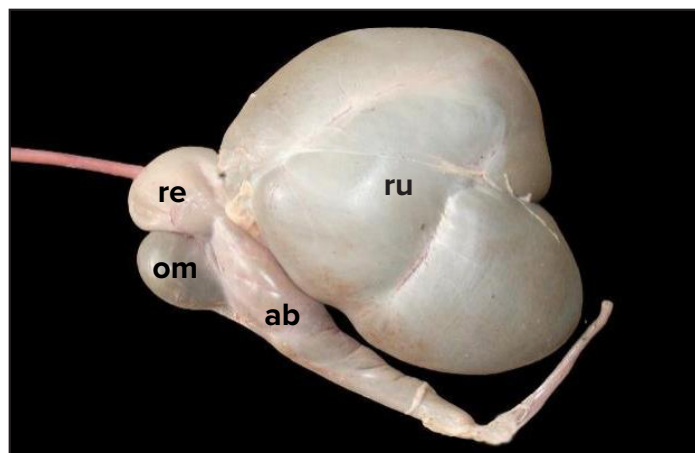


Figure 2. The four compartments of the ruminant digestive system are the reticulum (re), rumen (ru), omasum (om) and abomasum (ab). Photo by Dr. Luciano Alonso and Dr. Pedro Malafaia (UFRRJ).

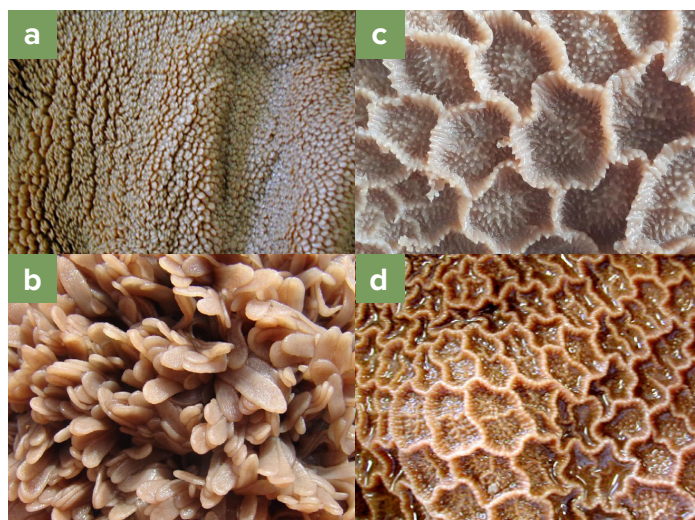


Figure 3. Interior characteristics of the rumen and reticulum. Rumen papillae (a, b) and reticulum honeycomb-like wall (c, d). Photos a and d by Dr. Karen Petersen (UW). Photos b and c by Dr. Luciano Alonso and Dr. Pedro Malafaia (UFRRJ).

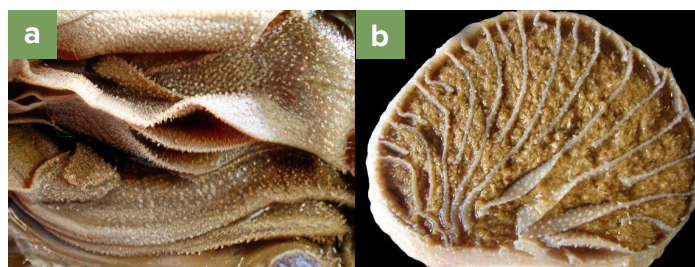


Figure 4. Omasum longitudinal folds (a) and a cross-section of the omasum filled with feed (b). Left photo by Photos by Dr. Karen Petersen (UW). Right photo by Dr. Luciano Alonso and Dr. Pedro Malafaia (UFRRJ).

Small and Large Intestine

The intestine follows the abomasum as further sites of nutrient absorption and is divided into two segments: the small intestine and the large intestine. The small intestine is further subdivided into the duodenum, jejunum and ileum, while the large intestine is subdivided into the cecum, colon and rectum (Figure 6).

The **small intestine** is a tube up to 150 feet long in a mature cow that serves as the primary site for postruminal digestion and absorption in ruminants. The digesta entering the small intestine is mixed with secretions from the pancreas and liver to aid in digestion. The intestinal wall contains numerous finger-like projections called villi that increase intestinal surface area for nutrient absorption. Muscular contractions mix the digesta and move it to the next section.

The **large intestine** has structure and motor activities to facilitate prolonged retention of digesta. This segment of the intestine provides an adequate environment for microbial growth, which also aids in the digestion of fibrous carbohydrates, synthesis of proteins and production of vitamin B. Additionally, the large intestine absorbs water, various electrolytes, VFAs, and then excretes the remaining material as feces from the rectum. The cecum is a large blind pouch at the beginning of the large intestine, approximately 3 feet long in a mature cow. The cecum serves little function in a ruminant, unlike its role in horses. The colon is the site of most of the water absorption in the large intestine.



Figure 5. The interior of the abomasum.
Photo by Dr. Luciano Alonso and Dr. Pedro Malafaia (UFRRI).



Figure 6. Overview of the gastrointestinal tract of a goat. The small intestine, large intestine and rectum are shown by the white line. Photos by Dr. Luciano Alonso and Dr. Pedro Malafaia (UFRRI).

Development of the Forestomach in Ruminants

The relative size and development of the forestomach compartments in ruminants change significantly with age. At birth, the forestomachs (rumen, reticulum and omasum) are small, nonfunctional, and account for only 39% of the total stomach volume (Figure 7). These compartments lack microorganisms, and the rumen papillae and the omasum folds are still rudimentary. In this phase of life, the calf's largest stomach compartment is the abomasum, constituting more than 50% of the total stomach area.

On the first day of life, the abomasum does not secrete acid or pepsinogen, which allows for the efficient absorption

of immunoglobulins (transferred by the colostrum) in the small intestine. The rumen and reticulum remain undeveloped and nonfunctional as long as the diet is restricted to milk. In calves, there is a structure called the **esophageal groove** located in the reticulum wall that allows milk to bypass the rumen and directly enter the omasum and abomasum. The calf nursing behavior causes a reflex action that closes the groove to form a tube-like structure (channel), which prevents milk from entering the rumen.

As the calf begins eating grain and forage, a microbial population will develop in the rumen and reticulum. The end

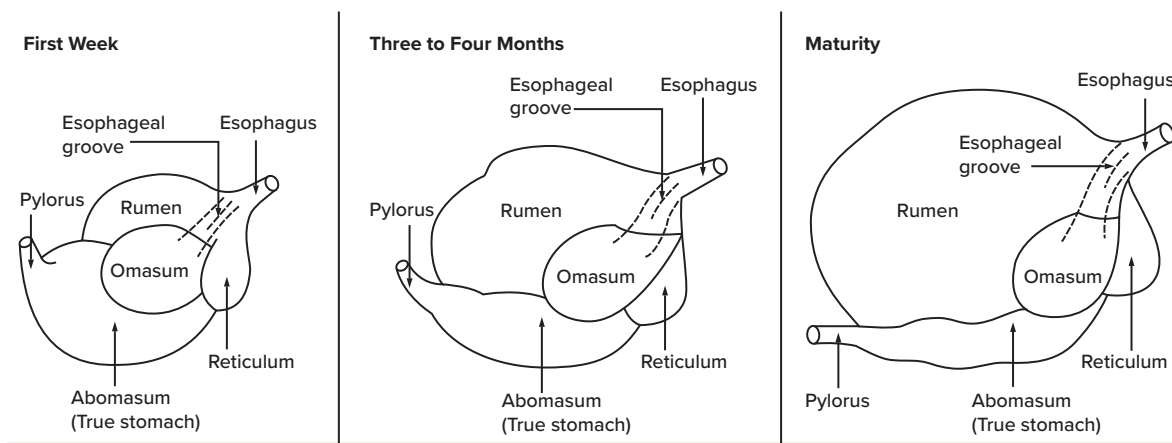


Figure 7. Development of the bovine stomach compartments from birth to maturity.

products from microbial fermentation are responsible for developing the rumen. Also, as the ruminant matures and transitions to solid feed, the esophageal groove loses its functional importance.

As the calf matures, the reticulorumen and omasum expand significantly, occupying a greater portion of the total stomach area.

In adult cattle, the abomasum accounts for only 14% of the total stomach capacity, while the reticulorumen and omasum represent 64% and 22%, respectively. During rumen development, the rumen papillae (which are responsible for nutrient absorption) become longer and fewer in number.

Dynamics of Digestion in Ruminants

Particularly in ruminants, the digestive system has the following functions: feed capture, chewing, rumination, salivation, swallowing, providing retention time, generating conditions for microbial growth in the rumen and intestines, digesting feed, absorbing nutrients, eructating fermentation gases and excreting indigestible residues.

As the feed gets to the rumen, it can be rechewed through the process of rumination and then swallowed again. When inside the reticulorumen compartment, the feed undergoes the process of fermentation which happens through microbial action. Those microbes digest the feed and use those nutrients for their own sake. The digestion by the microbes yields for the ruminants VFAs (energy-rich substance eliminated by microorganisms and absorbed by the rumen wall and the main source of energy for ruminants) and microbial protein (protein from microorganisms that escaped the rumen and started to be digested in the abomasum), which has high biological value. After a certain time retained in the reticulorumen compartment, the feed is pushed into the omasum

through the reticulo-omasal orifice for absorption of water and remaining VFAs (Figure 8).

The reticulorumen compartment has motility that helps mixing the digesta and facilitating the microbial activity, as well as separating and moving gases to the top of the rumen above the liquid fraction to be eliminated further. The process of eliminating gases (carbon dioxide, methane, and hydrogen sulfide) from the fermentation process is called eructation.

From the abomasum forward, the digestion process is very similar to that of humans and other simple stomach animals. There is enzymatic digestion produced by the ruminants and absorption of nutrients (Figure 8). The liver, pancreas and intestine produce enzymes that play important roles in the digestion in the small intestine. These enzymes break down protein, carbohydrates and lipids into smaller components (e.g., amino acids, glucose and fatty acids) that are small enough to cross the intestine wall and go to the bloodstream to be used by the body (Figure 9).

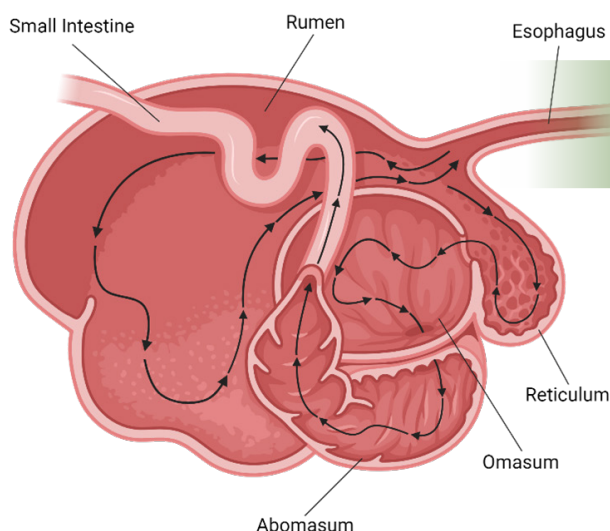


Figure 8. Kinetics and dynamics of the digestive process in the forestomaches, abomasum, and intestine. Graphic created by authors using BioRender

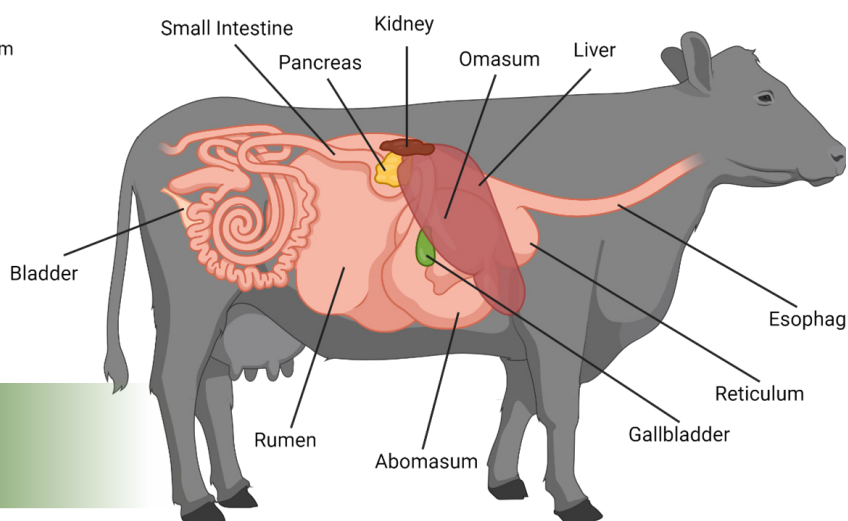


Figure 9. Ruminant digestive system and other organs involved in the process of digestion and metabolism. Graphic created by authors using BioRender.

References

National Academies of Sciences, Engineering, and Medicine. 2016. Nutrient Requirements of Beef Cattle, Eighth Revised Edition. Washington, DC: The National Academies Press. doi: 10.17226/19014.

Reddy, P.R.K., Hyder, I. 2023. Ruminant Digestion. In: Das, P.K., Sejian, V., Mukherjee, J., Banerjee, D. (eds) Textbook of Veterinary Physiology. Springer, Singapore. https://doi.org/10.1007/978-981-19-9410-4_14

Alonso, L. S., and P. Malafaia. 2024. Anatomy of the digestive system of ruminants (*Anatomia do sistema digestório dos ruminantes, com ênfase na clínica médica e na nutrição*). 1st ed. Universidade Federal do Rio de Janeiro (UFRRJ), Rio de Janeiro, Brazil.