BASICS OF RUMINANT ANIMAL NUTRITION

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Introduction

Cellulose is the main constituent of plant cell walls and is the most abundant carbohydrate on earth. With exception of some snails and arthropods, animals lack the necessary enzymes for the digestion of cellulose. Bacteria and fungi are the main cellulose digesters. Animals have coevolved with their feeds, and by different strategies, herbivores use plants as source of most nutrients. Ruminant animals exhibit a remarkable cooperation with microorganisms.

The ruminant digestive system allows a symbiotic relationship with microorganisms that make the use of plants cellulose feasible. In the symbiosis between ruminants and microorganisms, the animal provides the microbes a favorable environment. In return the microorganisms provide fermentation products that are absorbed and metabolized by the animals.

In addition to pregastric fermentation, ruminants are defined by the phenomenon of rumination. Rumination involves the regurgitation of previously ingested material, re-chewing, re-salivation and re-swallowing of the bolus. Rumination may be an advantage for herbivores that have to escape from predators, but for the most part re-mastication and re-salivation improve the rumen environment for the resident bacteria.

Digestive System Anatomy

Digestive anatomy of ruminants reflects the adaptation of each species to its environment, and particularly to diet. Species that evolved in environments where brushes or trees are the dominant vegetal substrata are more specialized in selecting the most nutritious parts of those plants; mainly fruits and sprouts. In the case of ruminants that evolved with grasses, the feeding strategy favors higher intakes of less nutritious feeds. Between these two there is a wide range of species with various adaptations. As a consequence of these different diets, a variety of anatomical and behavioral adaptation within ruminants should also be expected. We will concentrate on the parts of the digestive system that differ most obviously from non ruminants and on those anatomical characteristics that could give the keeper an idea of the type of diet and feeding behavior of a particular species.

Prehensile organs. The first part of the digestive system expresses in ruminants a large diversification, correlated with type of diet. Food selectivity is reflected in the prehensile organs such as lips, tongue, lower incisor teeth and the dental pad in front of the palate. Lips and tongue give us a good idea of feeding type; ruminants that are selectors (i.e. Giraffes) have lips and tongues that are more agile than those of grass eaters such as buffalo and cattle.

Stomach. The ruminant stomach is subdivided in four cavities: reticulum, rumen, omasum and abomasums, the first three of which comprise the forestomach. The forestomach lacks glandular mucosa, and it is the primary site of pregastric fermentation. Together with the rumen, the reticulum forms a morphophysiological unity called the ruminoreticulum. However, their mucosa differ in form, and consequently in function. In the reticulum, the mucosa forms an interesting pattern from where both its Latin and English names (honeycomb) originate. The mucosa is subdivided by intersecting crests, and the design is particularly accentuated in nonselective grazers. Due to the shape of reticular mucosa and the morphology of the organ, the reticulum functions as a trap of large ingested particles. The rumen is divided by grooves, where blood vessels and lymph nodes are found. The rumen's luminal surface is covered by papillae, which greatly enhance absorptive surface area. Rumen papillae changes form under different feeding conditions, apparently in response to the organic acids produced by fermentation.

The omasum is separated from the ruminoreticulum by a structure known as the reticulo-omasal orifice. Nutritionists consider this orifice the bottleneck of food passage. The omasum is a ball shaped organ divided by longitudinal laminae of different sizes that considerably increase the absorption surface of the organ. Its function is unclear, but it perhaps acts as a filter, reducing the amount of liquid that flows to the lower tract, as well as playing a role in absorption. The omasal mucosa has an absorptive epithelium similar to the rumen papillae.

The last compartment of the stomach, the abomasum, is lined with glandular mucosa, and its functions are comparable to those of simple stomachs.

The proportions between the parts of the stomach vary between species and stage of development. Young suckling animals have relatively small rumens and large abomasums.

The lower tract does not differ greatly from most other mammals. However, the cecum varies in size between species, being larger in animals with more selective feeding behavior.

<u>Stomach Development</u>

Ruminants born and raised in natural conditions have simultaneous access to their dams' milk and to vegetation. However, the proportions of these sources of nutrition change over time. Thus, their stomach needs to adapt to accommodate to this changing diet. The newborn is basically a non-ruminant animal, but by about two months of age, the ruminoreticulum must increase its size and change its mucosal lining in transition from a liquid and nutritionally dense diet to a fibrous and less nutrient-dense diet. Consequently the proportions of ruminoreticulum and abomasum will change during this time (Fig 1). The consumption of plants promotes the normal development of the forestomach and its function. Plant fiber has a stretching effect on the stomach, while the products of cellulose fermentation, especially butyrate, promote papillae development.

Reticular (Esophageal) grove closure. The reticular grove provides a mechanism for diversion of milk through the ruminoreticulum and directly into the abomasum, thereby precluding fermentation. During suckling a reflex response closes the reticular groove.

<u>Digestion</u>

Carbohydrates. The digestion of carbohydrates in the ruminoreticulum generates volatile fatty acids (VFA). These products of carbohydrates digestion supply about 2/3 of the caloric requirement of the host animal. Carbohydrates are broadly classified as structural and nonstructural, in reference to their function in plants. Nonstructural carbohydrates are represented by soluble sugars and starch. Both sugars and starch are rapidly fermented by the rumen microorganisms. Structural carbohydrates are fermented more slowly. The early fermentation of carbohydrates within the digestive tract precludes significant glucose absorption from the small intestine. Ruminants therefore are especially dependent on gluconeogenesis from VFA. Blood glucose concentration is in ruminants is approximately one-half that of non-ruminants.

Protein. Protein nutrition in ruminants is, by the presence of the rumen microorganisms, very different than that of other mammals. The rumen microorganisms provide both benefits and challenges in regard to protein nutrition. Microorganisms degrade amino acids (AA) yielding ammonia (NH_3) and their carbon skeletons, and re-synthesize their own constituent protein. The re-synthesis of protein constitutes an improvement in protein quality if the source of NH_3 is a lower quality protein or a non protein source such as urea. In contrast, when fed high quality protein, the effect of the microorganisms is clearly negative. The importance of this phenomenon is anatomically illustrated by the evolutionary adaptation represented by the reticular grove. Recall that this structure allows bypass of milk from the esophagus to the omasum.

Lipids. Certain lipids are particularly valuable in animal nutrition because their higher concentration of energy. Lipids are present in plants as structural or storage lipids. Structural lipids are the predominant type in those plants that mainly use starch for energy storage (i.e. corn), while storage lipids is the predominant form in oilseeds such as soybeans and sunflower. The fatty acid composition of these different types of lipid is different and should be considered when formulating diets. Lipids in the rumen undergo extensive hydrogenation reaching the intestine for absorption with a larger percentage of saturation. Besides the fact that fats are present in relatively low amounts in forages, the addition of fats in ruminant diets could be of great utility. The high energy density of fats makes them very suitable to boost energy content in diets of animals with poor body condition or low intakes. However, depending on the type of lipid, fats can have negative effects in rumen function. Fat addition above 5% has been associated with lower fiber digestion. However, this effect that can be avoided by techniques that increase the rumen bypass properties of fats.

Vitamins. Rumen microorganisms synthesize the B vitamins and vitamin K. Thus ruminants need only be provided with vitamins A, E and D in the diet. Dietary vitamin D is particularly important for ruminants that are housed in facilities with low exposure to sun radiation, or during the winter months in higher latitudes.

Common digestive disorders

Acidosis. Acidosis is commonly defined as pathologic blood acidity. In ruminants it more commonly refers to an intra-ruminal acidic condition. The etiology of acidosis could be defined by two phases, an increase in intake of readily fermentable carbohydrates together with an abrupt change in rumen microbial species followed by the absorption of large quantities of acids into the blood stream. In acute acidosis, rumen wall tissue is destroyed allowing systemic invasion of bacteria responsible for liver abscesses. The most classical external sign is laminitis due to the rupture of peripheral arterioles.

Bloat. A common disorder that could be described as the impossibility of release of the gas produced by ruminal fermentation. In acute cases the animal will die by asphyxia due to the pressure of the rumen against the lungs. The causes of the phenomena are several, the most common might be by ingestion of lush pastures of legumes, however, other causes may include intake of high concentrate diets, abscesses and obstructions.

Ketosis. Ketosis is particularly common in well fed animals that have a sudden increase in energy requirements, or in animals that are subject to a rapid weight loss. The syndrome appears usually in lactating animals, and is characterized by an increase in circulatory levels of ketone bodies. Excessive fatness at parturition should be avoided in order to minimize the occurrence of the syndrome. Excessive ketone synthesis is the result of an imbalance between acetyl CoA and oxaloacetate supplies.

Urinary calculi. This disorder is characterized by the formation of calculi in any part of the urinary tract. It has been associated with excessive dietary phosphorous in confined animals. The most obvious sign is the inability of urinate. If untreated, the urethra or bladder may rupture, releasing urine into the abdominal cavity producing a condition called water belly.

Feedstuff Analysis

Adequate diet formulation depends upon knowledge of nutrient requirements and composition of feed ingredients. Basic analysis of forages should include a fiber fraction characterization. Two analysis for fiber should be always performed; Neutral Detergent Fiber (NDF), and Acid Detergent Fiber (ADF). These two analyses determine the total amount of cell wall (fiber) and estimate fiber major components: cellulose, hemicellulose, and lignin. The NDF analysis separates cell wall from the cell contents, and is a useful estimator of intake. Acid detergent analysis separates the more readily digestible parts of the cell wall, hemicellulose and wall proteins from the fraction of the fiber that is more slowly digested. The ADF value correlates better with total digestibility of the feedstuff. Further estimates should include ether extract for lipid content and a nitrogen content determination for crude protein calculation. Because protein can be extensively altered in the rumen by microorganisms, an additional estimation could be done. The protein fraction in feedstuffs for ruminants can be further divided into rumen degradable and rumen un-degradable protein. The correct supply of both rumen degradable and protein that bypasses ruminal degradation is often very important, particularly for animals with elevated nutritional requirements. However caution should be applied in their use for species other than those from where the values were obtained. More precise adjustment of the diets would require mineral analysis and eventually vitamins or other compounds present in a particular feedstuff. The National Research Council's Nutrient Requirements series of publications provide invaluable information to those balancing rations for animals.

References

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Figure 1: Relative change in tissue weight (%) with age in days.