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RUMINEWS

MONOGRAPH

"Digestibility – How to increase it"

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INTRODUCTION

Over recent years ruminants have become notorious for their contribution to the production of greenhouse gases like carbon dioxide and methane. While true and founded, we can't split it from the fact that they also play a positive role for humans, thanks to their ability to transform grass into protein-rich food for human consumption. Ruminants are able to use, unlike humans, non-protein nitrogen and cellulosic fibers to produce meat, milk and fat. In a time when we need to "feed" over 7 billion people who inhabit Earth, scientists are striving to find a balance between technical breeding of ruminants and care for the environment. Focusing only on non-ruminant animal production, like poultry and swine, is no alternative because arable lands to feed them are becoming scarce for human food production. If ruminant feeding techniques were inattentive to the "waste" of nutrients, notably those not adequate for human food or monogastric feed, the economical need of higher performances required nutritionists to formulate rations also with proteins from soy and other legumes, and starch sources - mostly corn and cereals. These nutrients are in direct competition with human nutrition. In order to find an acceptable balance between technical and economical performance, environmental impact, and direct competition for food sources between rearing animals and humans, it becomes crucial to scrutinize the processes of rumen fermentation, and to find tools to improve the digestibility of the whole ration, and therefore animal production yield. In particular, it is key that both non-structural (starch and sugars) and structural carbohydrates (cellulose) be fermented in the rumen at the greatest possible extent.

RUMINAL FERMENTATION OF STARCH AND SUGAR

Although, from an ecological point of view, it would be preferable not to employ starches in animal feed (in particular those coming from grains), this is a difficult target. Dairy cows, especially in the first 100 days of lactation, have a great need of glucose to be converted into lactose to produce milk, and lactose is the first limiting factor for milk production. The more lactose is made available to the udder, the more milk the cow will be able to produce. The glucose required for the production of lactose is mainly produced by the liver, starting from propionate that comes from rumen fermentation of starch. A simplistic conclusion would lead to think that there might be an easy solution:

" ↑ starch → ↑ propionate → ↑ glucose → ↑ lactose → ↑ milk "

If it looks good, there are certain physiological limitations to consider. **First**: in order to increase the starch concentration in the ration, it is necessary to remove the equivalent amount of fiber in the ration. **Second**: removing fibers reduces the ruminal cycle, reduces the production of saliva, with the consequent reduction of rumen buffering capacity. **Third**: a possible accumulation of propionates and other short chain acids in the rumen may cause an increase in acidity and, together with the reduction of rumen buffering capacity, lead to ruminal acidosis. **Fourth**: propionates accumulation in liver cells causes a significant reduction of ingestion, which may cancel the expected benefits of replacing cellulose by starches. A more effective route is not to increase starch concentration in ration, but to increase the degradability of all carbohydrates in the rumen, so to use starches in smaller amounts. Dairy rations in the first half of lactation are typically formulated with a minimum concentration of starches (from 20% up to a maximum of 28%). Except for non-structural carbohydrate (NSC or NFC), those contained in the plant cell for which the NRC 2001 tables recommend a very broad range that goes from 36% to 44% of dry matter, there is no specific requirement for starch. When we have to feed a fresh cow we tend to privilege maize as a starch source, both for its concentration (70%) and because a part of it can pass the rumen and be absorbed in the small intestine directly as glucose (or degraded to lactic acid). Starch sources most used for dairy cow nutrition are maize, sorghum (similar to maize in concentration of starch and ruminal degradability), wheat and its derivatives, and barley. Legumes as field bean, protein pea and some corn by-products can also contribute to the dietary starch intake. Starch, which is a glucose polymer, is located in the endosperm of the grains (the structure that envelops the embryo and assures its nutrition until when it is able to assume the nutrients directly from the plot). Fats and proteins are also present in the endosperm. Starch is present as amylose and amylopectin, in granule form, covered by a protein matrix more or less complex. The vitreous endosperm contains a protein – prolamin - that is insoluble and very resistant to digestion. In some corn varieties named "very glassy", prolamin content is particularly high. In the rumen, starch is "hydrolyzed" into smaller units of maltose and glucose by specific and very prolific bacterial species through enzymes, such as alpha- and beta-amylase. Lactating cows often get high amounts of concentrates, rich in grains and starch, implicating on a high rumen turnover and short feed residence time in the rumen. A classic example is the maize grain. When a certain amount of this grain fed to a heifer and is fully degraded by the rumen, if that same amount is given to a cow near maximum milk production a major part the grains are found undegraded in the excrements, because of a short residence time in the rumen. Then, a first hint to increase rumen digestibility of cereals is to ensure that starch in the ration is quickly accessible to amylolytic enzymes of rumen bacteria. Feed processing technologies are used for that purpose, and grains used in lactating ruminant feeds are commonly grounded, flaked, rolled or partially fermented like silage. For cereals as wheat and barley even harsh grinding conditions (screen diameter below 3mm), flaking or silage-like fermentation, do not increase their rumen degradability due to the structure of starch in the endosperm. Maize and sorghum, quite differently, show significant ruminal degradability improvements when they are processed. However, we must remember that an increase in rumen degradability of starch, without a reduction in its concentration, significantly affects the fiber digestibility. For sugars the context is relatively simpler: if completely degraded in the rumen, they are not precursors of propionic acid and then of glucose, while the portion that passes the rumen undegraded can directly contribute to the glucose pool into the blood. Sugars represent an important growth factor for many bacterial species that colonize the rumen. In addition, butyric acid derived from sugar fermentation contributes to the efficiency of absorption of rumen epithelium and intestinal villi, and butyric acid is an important precursor of milk fat.

RUMINAL FERMENTATION OF FIBERS

Rumen fermentation of fibers (cellulose) brings several great advantages. The first is that the majority of the microbial biomass is constituted by ruminal bacteria that eat cellulose, and this biomass is extremely rich in essential amino acids. So, increasing the production of ruminal biomass increases the amount of ruminal protein available to the cows. The amino acid composition of rumen microbial biomass fits perfectly to the dairy cows requirements to synthetize all the casein to express their genetic potential. Second, an efficient rupture of plant cells allows the liberation of their internal nutrients: starches, proteins, fats and oligo elements. Plant cell walls are mostly made of hemicellulose and cellulose, both glucose polymers that are often classified as "crude fiber" (Weende method). Today they are more properly identified with the so-called "method of Van Soest" as NDF (neutral detergent insoluble fiber), ADF (acid detergent insoluble fiber) and ADL (roughly lignin). A simple calculation gives you the amount of hemicellulose in a feed, by subtracting NDF from ADF. Hemicelluloses are very degradable and represent an ideal fermentation substrate for the growth of bacteria that ferment fibers. When subtracting ADF from ADL you measure the amount of cellulose, the most abundant fibrous component. Lignin has a mechanical function and is not digestible by ruminants. All plant ingredients fed to ruminants go through the same degradation processes: first, must be soaked so it can be fermented; in the rumen fluid, it is surrounded by fibrolytic bacteria that hydrolyze plant cell walls and liberate simple sugars consumed for bacterial metabolism and multiplication. These and basic steps provide the key to understand the importance of certain concepts. Wet nutrients, like grass, silage or those moistened, are more easily and rapidly fermented. The more a fibrous feed is rich in hemicellulose, the higher will be the growth of cellulolytic bacteria. The more a source of fibers is grinded, the larger will be the surface area available for bacterial fermentation. The younger the fodder plants are, the thinner will be the cell walls and the lower lignin concentration.

HOW TO MANIPULATE RUMINAL FERMENTATION

Although the best solution to get the maximum growth of microbial biomass that ferment carbohydrates is to administer more degradable young fodder, ensiled forages, milled concentrates or heat processed, it is not always applicable both for technical or economical reasons. However, there are certain additives or compounds that can be used to increase the growth of ruminal biomass. The most common is nitrogen as true protein, meaning amino acids, but also in non-protein form, such as ammonia, nitrate or urea. All bacteria, protozoa, and fungi that proliferate in the rumen need nitrogen for their metabolism. Bacteria that ferment cellulose require almost exclusively non-protein nitrogen, while those that degrade starches require also true protein nitrogen sources. When we formulate diets for dairy cows, a good target is at least 5% of soluble protein and 11% of rumen-degradable protein. For medium-high starch concentrated rations it is advisable to add 100 grams of peptides or more. Rumen buffers are also important, compounds like sodium bicarbonate which are capable of stabilizing the rumen pH and bring sodium, useful for the absorption of fatty acids across the rumen wall. Although the presence of sodium bicarbonate in the saliva is very high it is recommended also to provide it through the diet, in quantities varying from 1% to 2% of dry matter. Maintaining a rumen pH around 6.00 is a fundamental condition to create a positive environment for the development of fibrolytics bacteria and improve fiber digestibility. Another group of additives are the DFM's (Direct-Fed Microbials), made of bacteria and fungi that can contribute to rumen fermentation. Among the DFM bacteria we find the propionibacteria, which increase the production of propionate and lactobacilli. Fungi are also very interesting. The most common in this category are the Saccharomyces cerevisiae family of yeasts, while Aspergillus oryzae and Aspergillus niger are getting growing attention over recent years. The mechanisms of action of these DFM are different if they are in viable form or inactivated. The viable Saccharomyces strains promote the use of ruminal lactic acid facilitating the growth of bacteria using lactic acid. More generally the use of 'live yeast' in dairy cows diet tends to increase the ingestion, the production of milk and health. But despite all the interest on viable DFM, the feed processing stress – high temperature and use of steam – make a serious application barrier and have been limiting the use and potential benefits of these products. Even more inte resting are the fermentation substrate of select Aspergillus strains, sometimes associated with inactive yeasts. With the adoption of special cultivation technique it is possible to enrich their fermentates with a comprehensive range of enzymes, including amylases, cellulases and xylanases. Dried and inactivated extracts of these fermentation substrates greatly favors the growth of fibrolytic bacteria, consequently the fiber digestibility and the use of lactic acid by the bacteria. While monogastric diets are often added of purified enzymes, this cannot be replicate in ruminants because that these proteic molecules would be rapidly destroyed by the rumen. The inactivated fermentate of Aspergillus also contain, beyond the additive type enzymes referred above, a range of secondary nutrients that act in parallel with enzymatic activities and contribute to an expanded overall benefit to rumen degradation performance.

Some others useful nutrients we can mention are sulfur, cobalt, biotin, and isoacids that stimulate the growth of rumen microflora.

CONCLUSIONS

The attention to the improvement of rumen fermentation have increased over the last years. Today, ecological and economic needs drive us to improve the dynamics of the rumen fermentation, through a better fodder quality, the reduction in the use of starch-rich concentrates, and the adoption of additives and compound formulations with verified action on rumen degradation results. All this for the benefit of the environment, the animals, and the profitability of farms.

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