FEEDING STARCH TO BROWSING RUMINANTS

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Introduction

This article summarizes the role of carbohydrates in ruminant nutrition, and the effect of starch in browsing herbivores.

Background

In the wild, browsing ruminants tend to select diet items including leaves, fruits, forbs and foliage from trees and shrubs, as opposed to grazing ruminants which tend to select grass and roughage. In order to effectively process these diet components, browsing ruminants generally have a relatively larger lower gastrointestinal tract than grazing ruminants, and the rumen is predicted to have less selective retention and more passage of available carbohydrate and protein to the lower GI tract (Van Soest, 1994).

Regardless of their type of feeding strategy, browsing and grazing ruminants have both evolved to utilize carbohydrate fractions of plants as energy sources, via anaerobic fermentation by gut microorganisms in the rumen. These microorganisms convert carbohydrate fractions into the end products of volatile fatty acids (VFA) and lactic acid. As previously stated, browsing and grazing ruminants choose different diet items in the wild, thus it is expected that they consume different types of carbohydrate fractions in their wild type diet.

The carbohydrate fractions of plants are a very diverse category of compounds, but generally include non-cell wall components (simple sugars involved in intermediary plant metabolism, and storage compounds such as starches and fructans), and cell wall components (including structural carbohydrates such as pectins, hemicellulose, cellulose and lignin). In general, non-cell wall components can be digested by mammalian enzymes, while cell wall components are digested via microbial fermentation. Thus, ruminants, unlike monogastric mammals, are capable of extracting energy from the cell wall components of plants (Van Soest, 1994). The profile of microorganisms in the rumen is based upon the type of carbohydrate fractions to which the animal is acclimated, and can change to some extent to accommodate new dietary components (Van Soest, 1994).

Starch and ruminant nutrition

Starch is the primary storage carbohydrate in plants, is a major component of many common feed ingredients including cereals, forage grasses (tropical grasses in particular) and legumes (Van Soest, 1994). Starch can be digested by mammalian and microbial enzymes. Mammalian enzymatic digestion results in the cleavage of starch to glucose units, which can be absorbed in the small intestine. On the other hand, microbial digestion of starch results in the production of lactic acid (Van Soest, 1994).

Starch fermentation in the rumen, and the associated production of lactic acid results in a decline in rumen pH due to inadequate buffering capacity, which can result in gastrointestinal disturbances (Van Soest, 1994). Acidosis resulting from excessive production of lactic acid can be classified as acute or chronic. Acute acidosis occurs as an overt illness generally following very high consumption of rapidly fermentable carbohydrates such as starch. Chronic acidosis generally does not result in overt illness, but can cause reduced feed intake and performance (Owens et al., 1998).

The rumenal epithelium, unlike that of the small intestine, is not protected by a mucus layer, thus even brief periods of acidosis can cause inflammations, ulceration and scarring (reviewed by (Owens et al., 1998)). As a result of ulceration, rumenal microbes can enter the blood, and are associated with liver abscesses. Additionally, tissues of the rumen that are subsequently repaired will be thickened, which can inhibit VFA absorptions rates for months or years after the acidotic incidence (Owens et al., 1998). In severe cases of acidosis, systemic tissue degradation is induced, causing inflammation of the hoof, lameness and in severe cases, hoof loss (reviewed by (Russell and Rychlik, 2001)).

In addition to effects of low pH on rumen and animal health, some starch-fermenting bacteria secrete polysaccharides, which cause gas accumulation in the rumen, and bloat. Mild cases of bloat can reduce performance, while severe bloat can cause mortality (reviewed by (Russell and Rychlik, 2001)). Fermentation of starch can also cause a release of free glucose into the rumen, which allows normally non-competitive microorganisms to grow rapidly, some of which produce and release endotoxins and amides. Additionally, free glucose in the rumen increases osmolality, which inhibits VFA absorption and thus can cause energy balance issues in ruminants (Owens et al., 1998). Finally, many ruminants have little endogenous amylase activity in the intestine, such that starch escape from the rumen can cause bacterial overgrowth in the small intestine, and lead to systemic disease (reviewed by (Russell and Rychlik, 2001)). However, moose were shown to have similar concentrations of carbohydrases in the pancreas and small intestine as do grain-fed cattle, suggesting that the capacity to utilize starch that has escaped from the rumen may be similar in browsing herbivores as compared to grazers adapted to starch-containing diets (Schochat et al., 1997).

Factors that can mitigate the effect of starch in the diet include dilution of the starch-rich diet with roughage, or modulating the intake of starch (Owens et al., 1998). Increasing the concentration of roughage in the diet increases chewing time, which affects the rumen in two ways. First, increased chewing will reduce particle size, which will actually increase the rate of fermentation, but second, chewing will increase the input of salivary buffers that can modulate or neutralize acidic conditions in the rumen (Owens et al., 1998). In addition to changing roughage and dietary starch levels, dietary rumen buffers can modulate the incidence of rumen acidosis (Owens et al., 1998). Monensin and other rumen buffers are routinely added to domestic cattle diets, particularly in the feedlot setting. Other rumen buffers have also been shown to have effects on rumen pH include dietary bicarbonate, probiotics and protein level (Owens et al., 1998).

Assessing rumen health

There are numerous measurements of rumen physiology that may be indicative of the health of the rumen. Many of these are invasive (e.g., rumen fluid collection for VFA, pH, microbial determination), or terminal (e.g., rumen histology), while others are less so (e.g., blood collection for VFA profiles). Rumen and blood VFA of interest include acetate, propionate, lactate and butyrate, and these generally change in response to diet. For example, forage-based diets generally result in higher acetate: propionate ratios than do cereal-grain based diets in cattle (Russell, 1998). Cereal-grain based diets generally result in lower rumenal pH, and this effect is magnified as feed intake increases (Russell, 1998).

Rumenal pH measurements may be difficult to interpret- in cattle, rumenal pH reaches it's lowest level at 6-10 hours post-feeding (Owens et al., 1998). Additionally, research into rumen pH has demonstrated that a single measurement of pH is not an effective guideline to judge the health or function of the rumen. In fact, when ruminants consume food, regurgitate, remasticate and ruminate, their rumen pH moves through a cycle of low (acidic) pH and neutral pH (e.g., (Dado and Allen, 1993)). Thus, a single measurement may detect a low or neutral pH, without any idea of where in the pH cycle that measurement occurred. For example, a ruminant whose pH moves from 5.5 to 7.0 would be considered to have a healthier rumen than an animal whose pH moves from 5.0 to 7.5. Another factor to consider is the time that it takes for the rumen to move from a low (acidic) pH to a neutral pH. The longer that the rumen is maintained in acidic conditions, the more likely that the animal is suffering from poor rumen health.

Effects of starch on rumen health

Domestic ruminants (generally grazing ruminants) in developed countries are routinely fed substantial quantities of starch-rich cereal grains in their diets. If a transition from forage-based diets to these grain-based diets occurs quickly, the rumen can become severely acidic due to the overgrowth of starch-fermenting, lactate-producing bacteria. Similarly, and perhaps more remarkably, browsing ruminants are hypothesized to have similar responses to diets high in starch, or to transitioning from low-starch to high-starch diets very rapidly.

In response to the potential health concerns related to feeding starch to browsing ruminants, commercially prepared, low starch diets have been introduced. Several research trials have determined that these diets are more suitable for browsing ruminants based on several parameters. For example, mule deer fawns fed a low starch diet (,4%) had lower propionate and butyrate, and higher acetate: propionate ratios in their blood compared to animals fed higher starch levels (12-24%) (McCusker et al., 2008). Since higher forage based diets are associated with higher acetate and lower propionate, and reductions in propionate are associated with reduced acidosis, these data support the hypothesis that low starch diets promote more optimal rumen physiology than do high starch diets. Similar results were obtained using in vitro culture systems with mule deer rumen fluid to examine a variety of dietary components (Brooks et al., 2008). Interestingly, this trial also demonstrated that rumen fluid from a dairy cow was not a suitable alternative to rumen fluid from the browsing mule deer. Finally, giraffe fed a low starch diet for 3 years have had correction of previously inverted blood calcium: phosphorus ratios, suggesting that rumen function and acid-base balance was improved (Koutsos et al., 2007).

Conclusions

It is clear that exotic ruminants have evolved to eat diets that are relatively low in starch. In captivity, for browsing and grazing ruminants, high starch diets can cause rumen dysfunction and systemic health concerns. Therefore, any time that starch is introduced into the diet of a captive ruminant, it should be done very slowly to allow for adaptations of the rumen environment, in order to prevent acute acidosis. Additionally, a diet low in starch is the best option for feeding captive browsing ruminants, and alleviates many of the concerns presented in this paper.

References

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