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AN331

Rumen Protozoa: The Animals within the Cow[1]

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As a cow ambles around and eats from the feed bunk, legions of other "animals" are feeding within the cow's rumen. Billions of protozoa swim about in a single, 20-gallon rumen, colliding with one another while engulfing feed particles and bacteria (Figure 1). The name protozoan means "first animal," reflecting the animal-like characteristics of these microbes. These microbes contribute vitally to rumen fermentation and have both positive and negative impacts on animal performance.

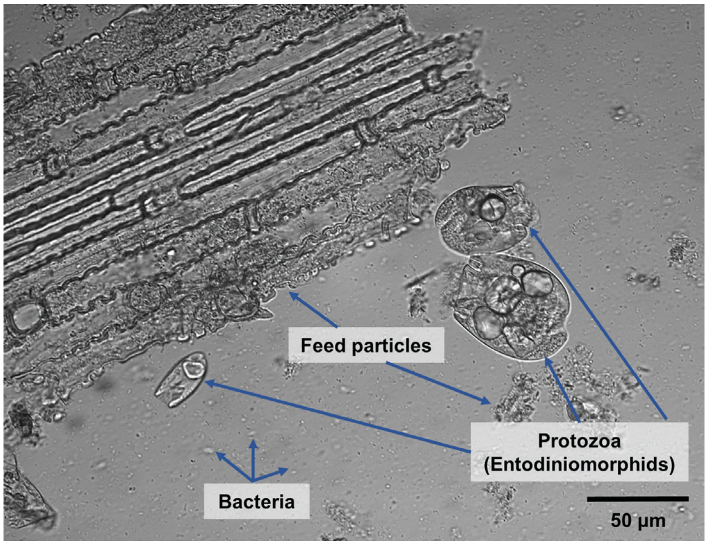

Figure 1. Rumen protozoa (entodiniomorphids). Feed particles and bacteria are also labeled. Distance represented by scale bar (50 µm) is about the width of a human hair.
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The protozoa make up 0.01% or fewer of these microbial cells in the rumen. Bacteria make up about 98% of cells, and fungi and methanogens account for the remainder (Lin, Raskin, and Stahl 1997). Though few in number, protozoa are relatively large; consequently, they make up between 5 to 50% of the mass of microbes in the rumen (Sylvester et al. 2005; Williams and Coleman 1992). Certain protozoa are large enough to see with the naked eye.

Classification

Hundreds of protozoal species have been identified (Williams and Coleman 1997), but most can be divided into two types (Figures 1 and 2). One type (isotrichid) is covered with fur-like cilia, which beat like oars and enable protozoa to move (Figure 2). This type consumes mostly sugars and other soluble carbohydrates (Williams and Coleman 1992). It does not engulf feed particles, but it can attach to them for access to carbohydrates inside. It can engulf fewer bacteria than the second major type of protozoan (Belanche et al. 2012). It has limited ability to degrade fiber (Williams and Coleman 1992).

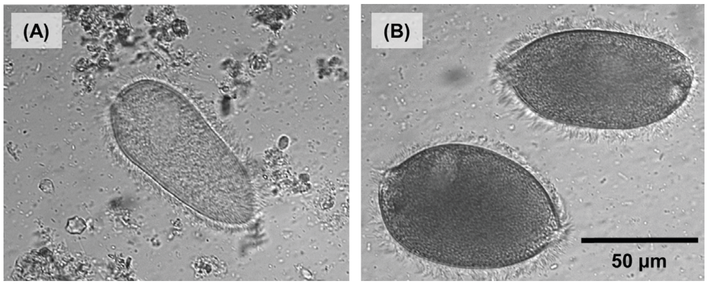

Figure 2. Rumen protozoa (isotrichids) with little (A) and abundant (B) reserve carbohydrate. Formation of carbohydrate was stimulated by giving cells glucose.
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1. This document is AN331, one of a series of the Department of Animal Sciences, UF/IFAS Extension. Original publication date January 2017. Visit the EDIS website at http://edis.ifas.ufl.edu.

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The second type of protozoan (entodiniomorphid) also has cilia, but in defined tufts (Figure 1). This type has one tuft located around its mouth, allowing it to engulf particulate matter (feed particles and bacteria). It degrades the fiber, starch, and insoluble protein abundant in this particulate matter (Williams and Coleman 1992; Belanche et al. 2012).

There is another type of protozoan (flagellate) (Ogimoto and Imai 1981), but it is thought to be less important than the two major types due to its smaller size (Figure 3). It has no cilia; instead, it moves with whip-like flagella.

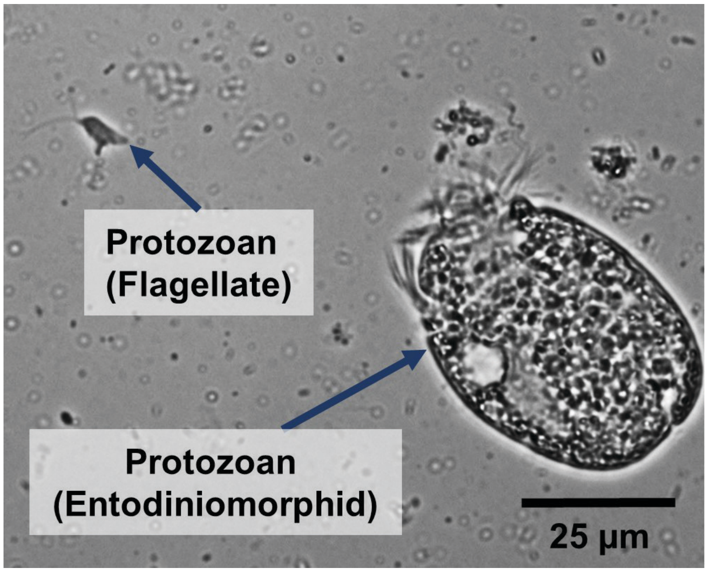

Figure 3. The minor type of rumen protozoan (flagellate) alongside one of the major types of protozoa (entodiniomorphid).
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Activities in the Rumen

After feeding, protozoa store large quantities of starch and starch-like reserves that are important to the cow and protozoa alike. They can store starch granules from feed directly, or they can form starch-like carbohydrate reserves (glycogen) from soluble feed carbohydrate. The isotrichids are adept at forming these reserves from soluble carbohydrate, storing enough to turn opaque (Figure 2). This protozoal starch is nutritionally important to the cow because some escapes from the rumen and becomes available for intestinal absorption. It also gives protozoa a competitive advantage over bacteria because it sequesters carbohydrate from bacteria. This sequestration may explain why protozoa are able to persist in the rumen, even though bacteria grow much faster than protozoa in laboratory culture (Denton et al. 2015).

Protozoa prey upon bacteria, giving them another competitive advantage. Protozoa incorporate some protein from engulfed bacteria into their own cells, but they break down some into peptides, amino acids, and ammonia and release these into the rumen (Jouany 1996). This decreases the supply of microbial protein to the cow (Williams and Coleman 1992).

Protozoa are frequently, if not unfairly, cited for increasing methane emissions from cattle. Methanogens, not protozoa, are the organisms that directly produce methane, but protozoa harbor methanogens on their cell surfaces and inside their cells (Stumm, Gijzen, and Vogels 1982; Newbold, Lassalas, and Jouany 1995; Finlay et al. 1994). During fermentation, protozoa produce hydrogen, which is channeled to the methanogens to produce methane. However, bacteria and fungi also produce hydrogen that is channeled towards methane. The relative impact of protozoa versus other microbes is not clear.

Most rumen microbes die in the presence of trace oxygen. Protozoa act to remove oxygen from the rumen (Williams and Coleman 1992). The rumen is mostly devoid of oxygen; however, some oxygen enters via feed and water and through the rumen walls. The isotrichids tolerate oxygen in low concentrations and can respire with it. This respiration removes oxygen, detoxifying the rumen environment for the isotrichids and other microbes. Unlike humans, isotrichids and related organisms do not generate energy (ATP) from respiring oxygen (Ellis et al. 1991; Müller et al. 2012). Thus, detoxification of the rumen environment, not energy generation, appears to be the reason for protozoal respiration.

Removal

Protozoa are not essential to the animal. They can be removed from the rumen by starvation and washing of the rumen with anti-protozoal agents (surfactants) (Williams and Coleman 1992). However, this removal technique (defaunation) is harsh and potentially detrimental to animal health. It is also easily undone by recolonization (refaunation) of protozoa from other animals. Although this removal is not practical for commercial feeding systems, it sheds light on the contribution of protozoa versus that of other microbes to rumen fermentation and animal performance.

Removing protozoa can be both beneficial and detrimental. Because protozoa degrade feed protein and prey upon bacteria that are also rich in protein, removing protozoa increases the supply of metabolizable protein to the animal. As a result, removing protozoa causes animals to grow faster when they are fed diets limited in protein. Wool growth increases for a similar reason (Williams and Coleman 1992). Because protozoa channel hydrogen to methanogens, their removal generally decreases methane production, although the response is variable (Hegarty 1998).

Removing protozoa decreases fiber digestibility, however, because bacteria cannot compensate for loss of protozoal activity towards fiber. This lowers energy availability and causes animals to grow more slowly when their diet is limited in energy (not protein) (Williams and Coleman 1992).

Impact on Animal Performance

Protozoal removal and other experimental approaches suggest that protozoa have both positive and negative impacts on fermentation and animal performance. The net impact varies with feeding conditions. The impact will likely be negative for growing animals on an energy-limited diet, but it will likely be positive for those on a protein-limited diet (Table 1). The net impact for lactating animals has not been examined experimentally, but it may follow the same pattern.

Table 1. Positive and negative impacts of protozoa on rumen fermentation and animal performance.

Positive Impacts	Negative Impacts
Increase fiber digestibility	Decrease supply of metabolizable protein
Remove oxygen, which is toxic to other microbes	Decrease animal growth when dietary protein is limited
Increase animal growth and efficiency when dietary energy is limited	

Because anti-protozoal agents are too harsh to routinely remove protozoa, there is little recourse when protozoa exert a net negative impact. Lipid has been suggested as an alternative to anti-protozoal agents because feeding lipid sharply reduces protozoal concentration (Hristov and Jouany 2005). However, lipid is expensive and can depress feed intake. Future research needs to refine the use of lipids or develop new anti-protozoal agents.

If protozoa are nonessential and sometimes impair animal performance, why do they inhabit the rumen at all? Rumen fermentation evolved about 40 million years ago under conditions far different from those of our modern feeding systems (Hackmann and Spain 2010). Perhaps protozoa offered a benefit to the ancestral ruminant that our experiments cannot reveal, or as rumen protozoologist Burk Dehority speculated, perhaps protozoa are there simply because they can be. More than 150 years after the discovery of rumen protozoa, these “first animals” continue to fascinate and mystify us.

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