Rumen

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The rumen is the first digester in the digestive system of ruminants, which is located on the left side of the abdominal cavity. Rumen occupying almost the entire left abdominal cavity. In its front part is the rumen vestibule, which connects with the esophagus through the cardia. Rumen microbes anaerobically ferment complex lignocellulose plant materials which cannot be directly utilized by a host, into monomers which are further degraded into different microbial end-products, including volatile fatty acids, hydrogen, carbon dioxide, methane, and other fermentation products necessary for essential metabolic pathways. The complex rumen microbiome network is dominated by bacteria, archaea, protozoa, and anaerobic fungi.

Keywords: anaerobic fungi ; methanogens ; lignocellulose ; methane

1.Introduction

The rumen is the first digester in the digestive system of ruminants. Its primary function is to briefly store feed and microbial fermentation. It is the predominant part of ruminants to digest food. The rumen occupies about 9%-13% of the body volume of ruminants and is the most essential digestive organ of ruminants. The digestive capacity of the rumen contributes 64%-71% to the entire digestive system. Most of the complex digestion processes are typically carried out in the rumen. The digestive enzymes in the rumen are secreted by microorganisms living in it. When food enters the rumen, a giant wide variety of rumen microbes immediately attach to the surface of the food. At the same time, the microbes continuously secrete cellulase, hemicellulase and β-glycosidase and other digestive enzymes that can hydrolyze lignocellulose. These enzymes can degrade polysaccharides such as cellulose, hemicellulose and pectin in food into monosaccharides, and gradually decompose them into volatile fatty acids and CO_2, among which volatile fatty acids can provide 60%-70% of ruminant’s energy source. Rumen microorganisms can digest lignocellulose efficiently. After full digestion, about 50% of crude fiber can be digested and degraded in the rumen. About 60%-80% of the energy requirements of ruminants are provided by the volatile fatty acids absorbed by the stomach wall. While lignocellulose is hydrolyzed during rumen fermentation, the rumen epithelium can absorb the volatile fatty acids expected to maintain the balance of water, nitrogen and mineral metabolism. Removal of volatile fatty acids is very vital to maintain the effective activity of microorganisms in the rumen.

The whole rumen provides a micro-oxygen environment, which can promote the growth of microorganisms in the rumen, thereby promoting the hydrolysis of lignocellulose. Digestion in the rumen is possible to facilitate the movement of feed sedimentation of fine particles, and it gets to the reticulum where the second stage fermentation, the large particles of undigested completely suspended in the upper reticulum, is circulated through the ruminant fermentation process.

The principal reason why ruminants can use higher fiber feeds more efficiently is that the rumen is rich in microorganisms. Initially, researchers believed that the principal microorganisms in the rumen that can degrade fiber are bacteria and ciliates. Until 1975, Orpin[1]discovered the existence of the rumen anaerobic fungi. At the same time, the researchers additionally discovered that the rhizoids of anaerobic fungi and the various carbohydrate-active enzymes secreted by them, which are the principal reason why rumen fermentation can efficiently degrade lignocellulosic biomass. According to the diverse living conditions in rumen, rumen microorganisms can be divided into four categories: (1) The microbial flora living in suspension in the rumen fluid mainly includes most of the microbial species; (2) The microorganisms attached and growing on the fermentation substrate mainly include most bacteria, fungi and a small amount of protozoa; (3) Colonize bacteria that grow on the rumen epithelium; (4) Bacteria that adhere to the surface of protozoa or fungal spores. Studies have demonstrated that up to 75% of rumen bacteria are attached to the surface of the degrading substrate. This indicates that the rumen fermentation process is usually in situ degradation. The combination of rumen microbes and the fibrous material in the substrate is crucial for the degradation of the substrate. The intermediate product after the fermentation substrate can be dissolved in the liquid phase for use by other microorganisms[2]. At present, researchers generally believe that a massive quantity of microorganism living in the rumen are mainly composed of anaerobic fungi, protozoa, bacteria and archaea[3].

2. Application of Rumen Microorganisms in Biomass Degradation

The synergy between the various microorganisms in the rumen fluid enables it to efficiently degrade a variety of lignocellulosic biomass. At present, researchers have done a lot of research on the degradation of biomass by rumen fluid in order to improve the efficiency of anaerobic digestion. The degradation substrates include paper mill sludge, cellulose part of municipal solid waste, agricultural waste and aquatic plants. In these studies, the addition of rumen fluid can enhance the degradation of substrate in varying degrees.

Rumen fluid is mostly used in anaerobic digestion of lignocellulose. In 1987, Gijzen et al. carried out anaerobic digestion of organic wastes from various sources and components by rumen microorganisms, including straw, bagasse, turfgrass, coffee pulp, paper mill sludge, paper mill pulping waste, vegetable auction waste, horticultural waste, mushroom residue, cellulose and organic part of municipal solid waste [4]. The results showed that the main products of rumen fermentation were volatile fatty acids and a small amount of biogas. The lignin degradation rate of various fermentation substrates is about 32%-48%. Baba et al. used rumen fluid as a pretreatment method to pretreat waste paper and then used for methanogenesis. The effect of pretreatment time of rumen fluid on methane production was investigated. The waste paper was soaked in rumen fluid at 37 ℃ for 6-24 h. A variety of volatile fatty acids, mainly acetate, were produced during the pretreatment[5]. The results showed that the daily methane yield of waste paper pretreated for 6 h was the highest, the total methane production was 2.6 times of that of untreated waste paper, and the actual methane production was 73.4% of the theoretical methane production. Pretreatment of rumen fluid can further improve the degradation rate of cellulose, hemicellulose and lignin. Zhang et al. also used rumen fluid pretreatment to improve the methanogenesis efficiency of rice straw. Under 39 ℃ anaerobic conditions, the best pretreatment time was 24 h[6]. Compared with the control, the biogas production increased by 66.5%, the methane production increased by 82.6%, and the digestion time was shortened by 40%. After anaerobic digestion, the total solid degradation rate and volatile solid degradation rate of rice straw pretreated with rumen fluid increased by 16.4%-33.3% and 14.8%-31.7% respectively. Xing et al. used rumen fluid for continuous anaerobic fermentation of wheat straw for 93 days. Under the continuous action of rumen microorganisms, degradation rates of cellulose, hemicellulose and lignin reached 97.6%, 95.8% and 42.4%, respectively[7]. Nguyen et al. compared the effects of rumen fluid and anaerobic sludge on the anaerobic digestion of four lignocellulosic biomass and found that due to the presence of hydrolytic and acid-producing bacteria in rumen fluid, the volatile fatty acids produced by rumen microorganisms in anaerobic digestion were 4 times higher than those in the anaerobic sludge reactor[8]. However, the biogas produced by anaerobic sludge as inoculant was more than that produced by rumen fluid reactor.

Rumen fluid is also used by researchers in the co-digestion of lignocellulosic biomass with other biomasses. Jin et al. chose to use rumen microorganisms for anaerobic co-digestion of corn stalks and pig manure. After 23 days of experiment, the continuous digestion reactor was successfully run with rumen microorganisms. The results showed that the retention time and dry matter content had little effect on the co-digestion performance, which confirmed that the rumen microorganism as inoculation could significantly improve the acidification and co-digestion of corn straw and pig manure[9]. In addition to lignocellulosic biomass, rumen fluid is also used in the anaerobic digestion of another biomass. For example, Budiyono et al. used rumen fluid as inoculum to improve the biogas yield of cow dung under medium temperature conditions, increasing the biogas yield and gas production efficiency by at least 2 times[10]. Baba et al. pointed out that methane produced by anaerobic fermentation of rapeseed pretreated with rumen fluid was 1.5 times higher than that produced by untreated rapeseed. The results of enzyme activity showed that the activity of cellulose decomposition enzyme and xylanase increased after 6 h, and the activity of oligosaccharide decomposition enzyme gradually increased after 24 h. It can be seen that rumen fluid as inoculation can significantly improve the anaerobic digestion effect of various biomass[11].

The application of rumen fluid in the anaerobic digestion of aquatic plants has also been studied in different aspects. For example, Yue et al. used digested sludge and rumen fluid as inoculants in the anaerobic reactor respectively for anaerobic digestion of aquatic plants, and the results showed that the inoculation of rumen fluid had a faster generation rate than sludge[12]. In addition to the application of rumen fluid in the anaerobic digestion of lignocellulosic biomass, some other cellulose-rich substances have also been attempted to be degraded and converted by rumen microorganisms. Takizawa et al. took rumen fluid as a pretreatment method, pretreated paper sludge at 37 ℃ for 6 h, and studied its influence on the anaerobic fermentation process of paper sludge[13]. The degradation and hydrolysis of paper sludge were significantly improved, and the methane produced by paper sludge after pretreatment was 3.4 times of that of untreated paper sludge. Lubberding et al. studied the application of rumen microorganisms in the anaerobic digestion of onion waste and pointed out that although the maximum loading rate was much lower than that of other cellulose substrates, the degradation rate could still reach 50% and 70% when the retention time of onion skin and onion pulp was 60 h[14].

References

1. Orpin, C. G; Studies on the rumen flagellate Neocallimastix frontalis. *Journal of general microbiology* **1975**, *91*, 249-62, 10.1099/00221287-91-2-249.
2. Craig, W. M.; Broderick, G. A.; Ricker, D. B.; Quantitation of microorganisms associated with the particulate phase of ruminal ingesta. *Journal of Nutrition* **1987**, *117*, 56-62, 10.1016/0308-8146(87)90116-6.
3. Kittelmann, S.; Janssen, P. H.; Characterization of rumen ciliate community composition in domestic sheep, deer, and cattle, feeding on varying diets, by means of PCR-DGGE and clone libraries. *Fems Microbiology Ecology* **2011**, *75*, 468-481, 10.1111/j.1574-6941.2010.01022.x.
4. Gijzen, H. J.; Lubberding, H. J.; Verhagen, F. J.; Zwart, K. B.; Vogels, G. D.; Application of rumen microorganisms for an enhanced anaerobic degradation of solid organic waste materials. *Biological Wastes* **1987**, *22*, 81-95, 10.1016/0269-7483(87)90041-3.
5. Baba, Y.; Tada, C.; Fukuda, Y.; Nakai, Y.; Improvement of methane production from waste paper by pretreatment with rumen fluid. *Bioresource Technol* **2013**, *128*, 94-99, 10.1016/j.biortech.2012.09.077.
6. Zhang, L.; Chung, J.; Jiang, Q.; Sun, R.; Zhang, J.; Zhong, Y.; Ren, N.; Characteristics of rumen microorganisms involved in anaerobic degradation of cellulose at various pH value. *Rsc Advances* **2017**, *7*, 40303-40310, 10.1039/c7ra06588d.
7. Xing, B. S.; Han, Y. L.; Wang, X. C. C.; Wen, J. W.; Cao, S. F.; Zhang, K. D.; Li, Q.; Yuan, H. L.; Persistent action of cow rumen microorganisms in enhancing biodegradation of wheat straw by rumen fermentation. *Science of the Total Environment* **2020**, *715*, 13, 0.1016/j.scitotenv.2020.136529.
8. Nguyen, L. N.; Nguyen, A. Q.; Johir, M. A.; Guo, W. S.; Ngo, H. H.; Chaves, A. V.; Nghiem, L. D.; Application of rumen and anaerobic sludge microbes for bio harvesting from lignocellulosic biomass. *Chemosphere* **2019**, *228*, 702-708, 10.1016/j.chemosphere.2019.04.159.
9. Jin, W. Y.; Xu, X. C.; Yang, F. L.; Li, C. L.; Zhou, M.; Performance enhancement by rumen cultures in anaerobic co-digestion of corn straw with pig manure. *Biomass and Bioenergy* **2018**, *115*, 120-129, 10.1016/j.biombioe.2018.05.001.
10. Budiyono, B.; Widiasa, I. N.; Johari, S.; Sunarso, S.; Increasing Biogas Production Rate from Cattle Manure Using Rumen Fluid as Inoculums. *International Journal of Science and Engineering* **2013**, *10*, 41-47, 10.12777/ijse.6.1.31-38.
11. Baba, Y.; Matsuki, Y.; Mori, Y.; Suyama, Y.; Tada, C.; Fukuda, Y.; Saito, M.; Nakai, Y.; Pretreatment of lignocellulosic biomass by cattle rumen fluid for methane production: Bacterial flora and enzyme activity analysis. *J. Biosci. Bioeng* **2017**, *123*, 489-496, 10.1016/j.jbiosc.2016.11.008.
12. Yue, Z. B.; Wang, J.; Liu, X. M.; Yu, H. Q.; Comparison of rumen microorganism and digester sludge dominated anaerobic digestion processes for aquatic plants. *Renew. Energy* **2012**, *46*, 255-258, 10.1016/j.renene.2012.03.030.
13. Takizawa, S.; Baba, Y.; Tada, C.; Fukuda, Y.; Nakai, Y.; Pretreatment with rumen fluid improves methane production in the anaerobic digestion of paper sludge. *Waste Managemen* **2018**, *78*, 379-384, 10.1016/j.wasman.2018.05.046.
14. Lubberding, H. J.; Gijzen, H. J.; Heck, M.; Vogels, G. D.; Anaerobic-digestion of onion waste by means of rumen microorganisms. *Biological Wastes* **1988**, *25*, 61-67, 10.1016/0269-7483(88)90128-0.