ID: 773

The Economic and Practical Considerations of Encapsulation in Ruminant Nutrition

Abdulhamid Muhammad GARBA[1]*, Sema YAMAN FIRINCIOĞLU[2]

[1]*Kano, Nigeria*
[2]Niğde Ömer Halisdemir University, Faculty of Agricultural Sciences and Technologies,
Department of Animal Production and Technologies, Niğde, Turkey
*Corresponding Author: abdulhamid.muhd@yahoo.com

Abstract
Technology involve in encapsulating nutrients is one of the reliable tools in ruminant nutrition that provide a better way in which nutrients are efficiently utilized, animal performance enhancement with a minimal negative effects to the environment. This study reviews the economic and practical implications of nutrient encapsulation in ruminant nutrition with an emphasis on its potential in bioactive compounds protection, controlled release of nutrients and feed efficiency improvement. Despite the benefits incorporation of encapsulation technology in ruminant nutrition brings such as sensitive nutrients stability enhancement and their systematic delivery in the ruminant digestive system, its uses in ruminant nutrition is associated with scalability limitation, high costs and practical challenges. The costs involved in encapsulation is higher when compared with the conventional additives because of the complexity of the materials involved in processing. Its integration relied on production scalability, stable storage and conformity with traditional feeding. Its economic feasibility depends on its importance in the performance and health of ruminant animals, or its environmental impact. Challenges involved in its practical application include consistency, technical know-how, and variability in performance of encapsulated products. Further researches are very important to reduce the costs and improve its delivery. Therefore, the encapsulation technology advancement in ruminant nutrition is reliant on achieving a balance between innovative solutions, cost-effectiveness and implementation practically at the farm level.
Keywords: Encapsulation, Economic, Costs, Ruminant, Nutrition

Introduction

Ruminant animals plays important in maintaining global food security, by providing meat, milk and other products that care for human nutrition (Xie et al., 2021). Nevertheless, the ruminant production is faced with several challenges such as inefficiencies in nutrient use, pollution to the environment, and rising costs related to feed. Therefore, enhancing feed efficiency and reducing losses of nutrients are very vital in ensuring ruminant production sustainability and productivity.

Encapsulation technology improves ruminant nutrition in a way of protecting and ensuring the targeted delivery of additives in feed. The process include enclosing the nutrient or additive in a protective layer of material ensuring that it bypass the rumen to the targeted digestive site (Garba & Fırıncıoğlu, 2023). It also ensures that unpalatable odors of the additives are masked and also protect sensitive nutrients and additives from degradation (Wei et al., 2022).

Studies from previous researches suggested the possible importance of encapsulation in improving ruminant nutrition. Example rumen protected amino acids (lysine, methionine) encapsulation was reported to improve milk production and synthesis of protein in dairy cattle (Zanton et al., 2014). Also the encapsulation of polyunsaturated fatty acids has been reported to increase their chances of integration into milk and meat without compromising rumen function (Jenkins et al., 2008). Encapsulation was also used to protect probiotics, enzymes, and phytogenic additives therefore, improving their efficiency and stability in ruminant diets (McAllister et al., 2011).

Encapsulation technology methods such as spray drying, coacervation, and extrusion have presented a wide range of application in ruminant nutrition. For example, encapsulation by spra-drying was used to protect essential oils which possesses an antimicrobial properties from rumen degradation (Benchaar et al., 2015). Coacervation encapsulation method was also used to protect vitamins and minerals ensuring their stability and bioavailability in diets of ruminant animals (Sanchez et al., 2017).

However, despite all these developments, there is a limited adoption of encapsulation technology in ruminant nutrition. With high costs of production, scalability and performance of encapsulated products variability, the commercialize application of these technology is difficult. There is also lack of standardized methods for evaluation of economic feasibility and efficiency of encapsulation technologies in ruminant nutrition.

While the potential benefits of encapsulation in ruminant nutrition are well-documented, several knowledge gaps remain. First, there is limited understanding of the interactions between encapsulation materials and rumen microbes, which can influence the release and utilization of encapsulated nutrients. Second, the long-term effects of encapsulated products on animal health and productivity require further investigation. Third, there is a need for cost-benefit analyses to evaluate the economic feasibility of encapsulation technologies in large-scale ruminant production systems. Finally, the environmental impacts of encapsulation materials and processes have not been thoroughly assessed.

The purpose of this paper is to provide a comprehensive review of the economic and practical considerations of encapsulation in ruminant feeding systems. By synthesizing existing literature, this paper aims to identify key factors influencing the efficacy and feasibility of encapsulation technologies, highlight potential challenges, and propose future research directions to optimize their use in ruminant nutrition.

Encapsulation Technology

Encapsulation is a technology in which nutrients, bioactive compounds and other nutrients components are enclosed in a protective coat or matrix. The technology is important in ruminant nutrition because of its ability to allow a targeted deliverance of vital feed and nutrients bioactive components and protecting them from rumen degradation hence ensuring their release in the lower digestive tract (Garba & Fırıncıoğlu, 2023). Biovailability, stability and efficiency of nutrients can be improve by encapsulation leading to the overall animal performance improvement and minimal environmental effects (Garba & Fırıncıoğlu, 2023).

Diiferent methods of encapsulation have been reported with each showcasing a promising advantages. Spray drying is particularly employed for heat sensitive compounds like essential oils, vitamins and probiotics through forming a dry particles often rapid drying (Ré, 1998). Coacervation is used for hydrophobic compounds such as fatty acids in which a separate colloidal phase is used to encapsulate the substances (Dong et al., 2011). Extrusion works for enzymes and probiotics (Kailasapathy, 2002). Liposome encapsulation technique uses lipid bilayers to enclose sensitive nutrients like vitamins (Mozafari et al., 2008), while emulsion-based methods help stabilize PUFAs and lipids (McClements, 2012).

Encapsulation of rumen protected methionine and lysine was reported to boost milk yield and milk protein content in dairy cows (Zanton et al. 2014). PUFAs encapsulation also enhance their transfer into milk and meat without compromising rumen function (Jenkins et al., 2008). This technology also allows for controlled nutrient release, improving absorption. Encapsulated starch, for example, provides post-ruminal energy, supporting better growth in beef cattle (Huntington et al., 2006). Additionally, encapsulation safeguards probiotics and enzymes, enhancing their stability and effectiveness. Protected probiotics have been shown to improve rumen health and overall animal performance (McAllister et al., 2011). Phytogenic additives such as essential oils often degrade in the rumen, but encapsulation ensures they reach the lower digestive tract intact, maximizing their antimicrobial and antioxidant benefits (Benchaar et al., 2015).

Economic Considerations

Production Costs: The high production costs associated with the implementation of encapsulation process is one of the factor that hinder its widespread adoption in ruminant nutrition especially by the small scale farmers (Xie et al. 2021). These high costs result from the complex nature of the encapsulation process because of the need for a specialized equipment and machines and the encapsulation materials (Xie et al., 2021). For example high quality lipids or polymers to be used in encapsulation can increase costs of production tremendously (Sánchez et al., 2017).

Cost-Benefit: Encapsulation allows nutrients such as amino acids, vitamins, minerals, enzymes, and probiotics to bypass rumen degradation and be released at optimal sites in the digestive tract. Nutrient bioavailability is increased by the target delivery which leads to better conversion of feed, weight, and milk production (Almassri et al. 2024: Garba & Fırıncıoğlu, 2023). Feed accounts for up to 70% of total cost of production in ruminant nutrition, therefore any improvement in feed efficiency can save cost and increase profit (Almassri et al. 2024). While encapsulation technologies can improve nutrient utilization and animal performance, their economic viability depends on the cost-benefit ratio. For example, the use of rumen-protected amino acids may be economically justified in high-producing dairy cows but not in low-producing animals. Similarly, the cost of encapsulating essential oils or probiotics must be weighed against the potential benefits in terms of improved animal health and productivity (Benchaar et al., 2015).

Scalability: Another important factor that influence the economic feasibility of encapsulation technology in ruminant nutrition is scalability, even though there is a cost effectiveness in a laboratory-scale encapsulation procedures, scaling up the processes for commercial production pose a challenge and it is expensive. For example, the production of encapsulated probiotics or enzymes on a large scale requires specialized equipment and stringent quality control measures, which can increase production costs (McAllister et al., 2011).

Practical Considerations

Technical challenges: The implementation of encapsulation technology in ruminant nutrition is faced with challenges involving the technical know-how including the appropriate encapsulation material selection, encapsulation process optimization and product stability and efficiency evaluation. The encapsulation material choice have effect on the release rate of the compounds encapsulated which also affects its efficiency in the rumen (Sánchez et al., 2017).

Variability in Performance: Encapsulation material type, size and structure of capsules, rumen condition are the factors that influence the performance of the encapsulated products. This variability makes it difficult to determine

the encapsulated products efficiency in different feeding systems. McAllister et al. (2011) reported that probiotics encapsulated efficiency may vary depending on the rumen microbial activity and pH.

The impacts of encapsulation materials and process on the environment have not been thoroughly evaluated. Biodegradability and environmental persistence as a result of the use of synthetic polymers as an encapsulation material may raise environmental concern. The production of encapsulation materials may also generate waste and emissions leading to environmental pollution (Sánchez et al., 2017).

Conclusion

Encapsulation technology offers several importance in ruminant nutrition such as improved nutrient utilization, animal performance enhancement and minimal environmental impacts. Nevertheless, its adoption in ruminant nutrition is hindered by high costs of production, technical know-how, and limited scalability. It's recommended that future studies should focus on finding and developing a cost-effective and scalable encapsulation processes, long-term effects of encapsulated products on animal health and productivity evaluation as well as evaluating the impacts of encapsulation material and processes to the environment

References

Almassri N, Trujillo FJ and Terefe NS (2024). Microencapsulation technology for delivery of enzymes in ruminant feed. Front. Vet. Sci. 11:1352375. doi: 10.3389/fvets.2024.135237

Benchaar, C., Calsamiglia, S., Chaves, A. V., Fraser, G. R., Colombatto, D., McAllister, T. A., & Beauchemin, K. A. (2015). A review of plant-derived essential oils in ruminant nutrition and production. Animal Feed Science and Technology, 145(1-4), 209-228.

Dong, Z., Ma, Y., Hayat, K., Jia, C., Xia, S., & Zhang, X. (2011). Morphology and release profile of microcapsules encapsulating peppermint oil by complex coacervation. Journal of Food Engineering, 104(3), 455-460.

Garba, A. M., & Fırıncıoğlu, S. Y. (2023). Role of Encapsulation Nutrients for Improvement of Ruminant Performance and Ruminant Derived–Products. Eurasian Journal of Agricultural Research, 7(2), 109-126.

Huntington, G. B., Harmon, D. L., & Richards, C. J. (2006). Sites, rates, and limits of starch digestion and glucose metabolism in growing cattle. Journal of Animal Science, 84(Suppl 13), E14-E24.

Jenkins, T. C., Wallace, R. J., Moate, P. J., & Mosley, E. E. (2008). Board-invited review: Recent advances in biohydrogenation of unsaturated fatty acids within the rumen microbial ecosystem. Journal of Animal Science, 86(2), 397-412.

Kailasapathy, K. (2002). Microencapsulation of probiotic bacteria: Technology and potential applications. Current Issues in Intestinal Microbiology, 3(2), 39-48.

McAllister, T. A., Beauchemin, K. A., Alazzeh, A. Y., Baah, J., Teather, R. M., & Stanford, K. (2011). Review: The use of direct fed microbials to mitigate pathogens and enhance production in cattle. Canadian Journal of Animal Science, 91(2), 193-211.

McClements, D. J. (2012). Nanoemulsions versus microemulsions: Terminology, differences, and similarities. Soft Matter, 8(6), 1719-1729.

Mozafari, M. R., Khosravi-Darani, K., Borazan, G. G., Cui, J., Pardakhty, A., & Yurdugul, S. (2008). Encapsulation of food ingredients using nanoliposome technology. International Journal of Food Properties, 11(4), 833-844.

Ré, M. I. (1998). Microencapsulation by spray drying. Drying Technology, 16(6), 1195-1236.

Sánchez, A., Mengíbar, M., Rivera-Rodríguez, G., Moerchbacher, B., & Acosta, N. (2017). The effect of preparation processes on the physicochemical characteristics and antibacterial activity of chitooligosaccharides. Carbohydrate Polymers, 157, 251-257.

Xie F, Jin W, Si H, Yuan Y, Tao Y, Liu J, et al. An integrated gene catalog and over 10,000 metagenome-assembled genomes from the gastrointestinal microbiome of ruminants. Microbiome. (2021) 9:137. doi: 10.1186/s40168-021-01078-x

Zanton, G. I., Bowman, G. R., Vázquez-Añón, M., & Rode, L. M. (2014). Meta-analysis of lactation performance in dairy cows receiving supplemental dietary methionine sources or postruminal infusion of methionine. Journal of Dairy Science, 97(11), 7085-7101.