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Role of Encapsulation Nutrients for Improvement of Ruminant Performance and Ruminant Derived – Products

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Abstract

Encapsulation nutrient technology has emerged as a transformative approach to enhance ruminant nutrition and improve the quality of products derived from ruminants. This method involves the protection of sensitive compounds through encapsulation, enabling controlled release and targeted delivery. In the realm of ruminant nutrition, encapsulation has led to improved nutrient utilization, reduced wastage, and enhanced animal performance. It safeguards essential nutrients, including vitamins, minerals, probiotics, and additives, from rumen degradation, ensuring optimal health and growth. Moreover, in ruminant-derived products, encapsulation practices have contributed to superior product quality by enhancing taste, texture, and shelf life. It can mask unpalatable compounds, release flavor enhancers, and reduce oxidation in meat and dairy products. However, the broader implementation of encapsulation technology faces challenges related to cost, formulation complexities, and regulatory approval. Addressing these obstacles and fostering sustainable practices will be crucial in realizing the full potential of encapsulation technology in the ruminant and ruminant-derived product industries. Future research should focus on sustainable materials, cost-effective methods, and tailored solutions for different ruminant species, bioavailability studies, methane mitigation technologies, and long-term health assessments. Furthermore, education, interdisciplinary collaboration, and the development of regulatory standards are essential to ensure the safe and effective use of encapsulation technology in ruminant and ruminant-derived products.

Keywords: Encapsulation Technology, Ruminant Nutrition, Ruminant-Derived Products, Nutrient Protection, Feed Additives

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INTRODUCTION

Ruminants, including cattle, sheep, and goats, play a vital role in global agriculture, contributing to the production of meat, milk, and other essential products (Kumar et al., 2017). However, optimizing their nutrition and enhancing the quality of ruminant-derived products pose ongoing challenges. Encapsulation nutrient technology, a versatile and innovative approach, has gained prominence in addressing these challenges by improving ruminant nutrition and the quality of products obtained from them (Khezri et al., 2016).

The encapsulation process involves the entrapping of bioactive compounds within a protective matrix, enabling controlled release, targeted delivery, and preservation of the compounds until they reach their desired destinations (Mehta et al., 2017).

Previous studies have shown significant potential in the use of encapsulation technology for the improvement of livestock products. Researchers have explored different encapsulation methods and materials to effectively deliver essential nutrients, improve feed efficiency, and enhance animal well-being (Grilli et al., 2013; Hu et al., 2015; Kim et al., 2020; Konkol and Wojnarowski, 2018; Natsir et al., 2019; Stamilla et al., 2020; Tao et al., 2020). Encapsulated probiotics, for example, have been shown to promote gut health and boost the immune system of livestock, leading to improved growth rates and reduced disease incidence (Rajam & Subramanian, 2022). Additionally, encapsulation of volatile compounds in animal feed has the potential to minimize feed wastage and reduce the environmental impact of livestock farming (Adineh et al., 2020)

In addition to its role in ruminant nutrition, encapsulation technology has found application in ruminant-derived products, such as meat and dairy. It has the capacity to enhance the sensory attributes and shelf life of these products, leading to increased consumer satisfaction and marketability (Yu et al., 2020). By masking unpalatable compounds, releasing flavor enhancers, and reducing oxidation in meat and dairy, encapsulation technology has paved the way for improved product quality.

While the application of encapsulation technology in ruminant nutrition and products holds significant promise, it is essential to consider the existing gaps and challenges in this field. These include cost considerations, formulation complexities, and regulatory approval, which may hinder the broader implementation of this technology. Addressing these obstacles is crucial for realizing the full potential of encapsulation technology in ruminant and ruminant-derived products.

The purpose of this review is to explore the current state of encapsulation nutrient technology in ruminant nutrition and products, highlighting its potential benefits and addressing the challenges that need to be overcome for its successful implementation. By examining the existing knowledge, identifying scientific gaps, and proposing future directions, we aim to contribute to understanding how encapsulation technology can positively impact ruminant farming and the quality of ruminant-derived products.

DEFINITION OF ENCAPSULATION

Encapsulation is a process that involves enclosing one substance within another, typically using a protective shell or carrier material. In the context of ruminant nutrition, encapsulation is used to protect and deliver specific nutrients, such as vitamins, minerals, and probiotics, to ruminant animals. The encapsulating material can vary, including polymers, lipids, proteins, or a combination of these (Akhavan, 2018).

PRINCIPLES OF ENCAPSULATION IN RUMINANT NUTRITION

Nutrient Protection: Encapsulation offers a protective barrier that shields sensitive nutrients from degradation in the harsh conditions of the rumen. This ensures that valuable nutrients, such as heat-sensitive vitamins, can reach the lower digestive tract intact (Nocek, 2017).

Targeted Release: Encapsulation can be designed to release nutrients at specific sites within the ruminant's digestive system. This controlled release enables better absorption and utilization of nutrients, promoting optimal ruminant health (Taghvaei et al., 2021).

Enhanced Bioavailability: Encapsulation technology can enhance the bioavailability of nutrients. By protecting them from ruminal degradation, more of the nutrients can be absorbed in the abomasum and small intestine, where they are most effective (Gupta et al., 2021).

Minimizing Environmental Impact: The use of encapsulated nutrients can reduce the environmental impact of ruminant farming. By preventing the excretion of excess nutrients into the environment, encapsulation can help mitigate issues like nutrient runoff and its associated environmental problems (Hadjipanayiotou, 2000).

Improved Feed Efficiency: Encapsulation can improve feed efficiency by ensuring that the nutrients are delivered to the site where they can be most effectively utilized. This can lead to increased weight gain and milk production in ruminants (Hosseini et al., 2020).

Encapsulation technology has various applications in ruminant nutrition, including the delivery of vitamins, minerals, and other bioactive compounds. It has been used to address specific nutritional challenges in ruminant diets, such as the need for controlled release of nutrients or the protection of sensitive compounds from rumen degradation. These applications have the potential to improve ruminant health, productivity, and overall well-being (Mehdi et al., 2018).

METHODS OF ENCAPSULATION

Encapsulation is a rapidly advancing technology that involves enclosing an active core material, which can be in liquid, gas, or solid form, within a protective barrier made of substances like a matrix or shell. This process results in the creation of capsules at various size scales, including nano, micro, or macrocapsules. There are three main categories of encapsulation: microencapsulation, which ranges in size from 0.2 to 5 µm; nanoencapsulation, with dimensions between 200nm and less than 0.2 µm; and macroencapsulation, which exceeds 5 µm in size. According to a report by Cosco (2006), microencapsulation is the most commonly used method within these capsule-size categories. The following are various encapsulation techniques used in ruminant nutrition.

Coacervation

Coacervation is a method of encapsulation that involves the phase separation of a polymer from a solution. In ruminant nutrition, this technique is used to create microcapsules that can protect sensitive nutrients. Coacervation has been applied to encapsulate vitamins, minerals, and essential fatty acids, allowing them to pass through the rumen unharmed and be absorbed in the abomasum and small intestine (Tamine et al., 2019).

Spray Drying

Spray drying is a widely used encapsulation method in ruminant nutrition. It involves the conversion of a liquid feed additive into a powder by spraying it into a hot drying chamber. This process forms small particles with a protective shell that can safeguard nutrients from ruminal degradation. The encapsulated nutrients are released and absorbed in the lower digestive tract, improving their bioavailability (Mitra et al., 2018).

Extrusion

Extrusion encapsulation is a method that combines heat, shear, and pressure to create a protective matrix around nutrients. This technique is commonly used to produce feed pellets containing encapsulated additives. It allows for the controlled release of nutrients in the digestive system, optimizing their utilization by ruminants (Anwari et al., 2020).

Electrospinning

Electrospinning is a relatively novel encapsulation method with applications in ruminant nutrition. It involves the creation of nanofibers through the application of an electric field. These nanofibers can encapsulate bioactive compounds and release them gradually in the digestive system, offering a promising approach to improve nutrient delivery (Bian et al., 2021).

Emulsification and Solvent Evaporation

Emulsification and solvent evaporation is another method used for encapsulating nutrients in ruminant nutrition. It involves dissolving the nutrient in a suitable solvent, emulsifying it in a polymer solution, and then evaporating the solvent to form microcapsules. This technique offers a versatile approach to protect nutrients from rumen degradation and enhance their bioavailability in the lower digestive tract (Azari et al., 2019).

Alginate Beads

Alginate beads are a type of encapsulation where a nutrient solution is mixed with alginate and then dropped into a solution containing calcium ions. This results in the formation of gel-like beads that encapsulate the nutrient. Alginate beads have been used in ruminant nutrition to protect and deliver nutrients such as enzymes or probiotics, ensuring their controlled release in the digestive system (Mehrotra et al., 2017).

Nanoparticles

Nanoparticles are extremely small structures used for encapsulation in ruminant nutrition. They offer the advantage of being able to encapsulate nutrients at the nanoscale. This enables efficient protection from ruminal degradation and enhanced bioavailability, especially for trace minerals and certain vitamins (Gupta et al., 2021). Encapsulation methods in ruminant nutrition provide a range of options to protect and deliver essential nutrients effectively. Coacervation, spray drying, extrusion, electrospinning, emulsification, and other techniques have been instrumental in improving nutrient delivery, enhancing ruminant health, and optimizing the quality of ruminant products.

MATERIALS COMMONLY USED IN ENCAPSULATION

Encapsulation is a vital technology in ruminant nutrition, and the selection of appropriate materials and an understanding of factors influencing encapsulation efficiency are crucial for optimizing nutrient delivery in these animals. The choice of encapsulating materials significantly impacts the effectiveness of encapsulation in ruminant nutrition. Commonly used materials include:

Polymers: Polymers like alginate, chitosan, and pectin have been used extensively in ruminant nutrition. Alginate beads, for example, have been employed to encapsulate probiotics and enzymes, protecting them from ruminal degradation and ensuring controlled release in the abomasum and small intestine (Oliveira et al., 2019).

Lipids: Lipids are employed to create lipid-based microparticles and nanoparticles. They offer protection for fat-soluble vitamins and essential fatty acids, allowing for their targeted release and improved bioavailability (Lemos et al., 2016).

Proteins: Proteins, such as whey protein concentrate, casein, and soy protein isolate, have been used for encapsulating bioactive compounds like antioxidants and amino acids. Protein-based encapsulation can enhance the stability and release properties of the encapsulated substances (Kumar et al., 2018).

EXAMPLES OF FEED ADDITIVES THAT ARE ENCAPSULATED TO IMPROVE RUMINANT AND RUMINANT-DERIVED PRODUCTS

Encapsulation technology has been employed to enhance ruminant nutrition and improve the quality of ruminant-derived products by protecting and delivering various feed additives. Below are examples of feed additives that are encapsulated for this purpose.

Probiotics and Prebiotics: Probiotic microorganisms and prebiotic compounds are often encapsulated to protect them from the harsh conditions of the rumen. This ensures their targeted release in the lower digestive tract, promoting a balanced gut microbiota in ruminants (Zhu et al., 2018).

Vitamins and Minerals: Encapsulation of vitamins and minerals protects them from rumen degradation, ensuring their availability for absorption in the small intestine. This enhances overall nutrient utilization and supports ruminant health (Górka et al., 2021).

Essential Fatty Acids: Encapsulated essential fatty acids, such as omega-3 and omega-6 fatty acids, are incorporated into ruminant diets to protect them from ruminal degradation. This leads to improved absorption and enhanced health parameters in ruminants (Yáñez-Ruiz & Martín-García, 2018).

Enzymes: Encapsulated enzymes, such as cellulases and hemicellulases, are used to enhance the digestibility of fibrous feed ingredients in ruminant diets. This technology improves feed utilization and animal performance (Santana et al., 2015).

Antioxidants: Encapsulation of antioxidants, such as vitamin E or plant-derived polyphenols, is used to reduce oxidative stress in ruminants and enhance the shelf life and sensory attributes of ruminant-derived products (Soares et al., 2020).

These examples demonstrate how encapsulation technology is applied to protect and deliver a range of feed additives, leading to improved ruminant nutrition, health, and the quality of ruminant-derived products. Encapsulation helps overcome challenges associated with rumen degradation, ensuring that these additives achieve their intended effects in the digestive tract.

FACTORS INFLUENCING ENCAPSULATION EFFICIENCY

Encapsulation efficiency refers to the extent to which the encapsulation process successfully entraps the active compound within the carrier material. Several factors influence encapsulation efficiency in ruminant nutrition:

Polymer Concentration: The concentration of the encapsulating polymer affects encapsulation efficiency. Higher polymer concentrations can provide better protection, but they may also reduce the release rate of nutrients (Das et al., 2019).

pH and Ionic Strength: The pH and ionic strength of the encapsulation solution can affect the interaction between the polymer and the nutrient. Optimizing these parameters is crucial for efficient encapsulation (Gan et al., 2020).

Particle Size and Morphology: The size and morphology of encapsulated particles are important factors. Smaller particles with a more uniform size distribution tend to have higher encapsulation efficiency (Taghvaei et al., 2021).

Stability of the Active Compound: The stability of the nutrient or bioactive compound during the encapsulation process is crucial. Some compounds may be sensitive to heat, moisture, or shear forces, which can affect encapsulation efficiency (Hosseini et al., 2020).

Encapsulation Technique: The choice of encapsulation technique (e.g., coacervation, spray drying, or extrusion) can impact encapsulation efficiency. Each technique has its own advantages and limitations, affecting the success of nutrient encapsulation (Noval et al., 2018).

The choice of materials for encapsulation and a comprehensive understanding of factors influencing encapsulation efficiency is crucial for optimizing nutrient delivery in ruminant animals.

RUMINANT NUTRITION ENHANCEMENT USING ENCAPSULATION TECHNOLOGY

Encapsulation for Rumen Bypass: Encapsulation involves the entrapping of nutrients within protective matrices, affording resistance to ruminal degradation. This technology enables the targeted delivery of sensitive nutrients, notably amino acids, vitamins, and minerals, to the lower digestive tract. Consequently, it enhances nutrient utilization, as evidenced by the capacity of microencapsulated amino acids to augment protein synthesis and milk yield in dairy cattle (Gott et al., 2015). Encapsulated nutrients and feed additives are essential for improving animal productivity because they increase the ability to bypass the rumen and reach the intended target. EC promotes the stability and bioavailability of phenolic compounds by serving as a barrier between them and other food components including protein and amino acids as reported by Silva *et al,* (2018). An experiment involving dairy cattle focused on studying how encapsulated amino acids could bypass the rumen and protect them from degradation within it. These encapsulated amino acids were integrated into the diet to ensure they remained intact in the rumen. The outcome of the study indicated a notable enhancement in protein synthesis and a corresponding increase in milk production among dairy cows, underscoring the efficacy of encapsulation technology in facilitating rumen bypass (Bach et al., 2007).

In a sheep nutrition case study, research utilized encapsulation technology to successfully enable essential fatty acids to bypass the rumen. These encapsulated fatty acids were incorporated into the diet to shield them from degradation within the rumen. As a result of this method, there was a noticeable improvement in the absorption of fatty acids, which subsequently led to enhanced health indicators in the sheep (Yáñez-Ruiz et al., 2018). Another study on mineral nutrition in beef cattle explored the use of encapsulation for rumen bypass of essential minerals. Encapsulated minerals were added to the diet to ensure their passage through the rumen intact. The study revealed improved mineral bioavailability and overall health in the cattle (Spears, 2017). Encapsulated vitamins were provided in the diet of goats to protect them from ruminal degradation. The study demonstrated increased vitamin absorption and improved health outcomes in the goats (Abdouli et al., 2020).

Encapsulation for Targeted Nutrient Delivery: Encapsulation, a cutting-edge technology, facilitates the creation of nanoscale carriers for nutrients. These nanocarriers can be precisely directed to specific regions of the digestive tract, optimizing nutrient absorption while minimizing wastage. Recent research underscores the capacity of nanoencapsulated essential oils to ameliorate feed intake, rumen fermentation, and milk production in dairy cattle (Wang et al., 2019).

A study on dairy cows investigated the use of encapsulation for the targeted release of minerals. Encapsulated mineral supplements were included in the diet to enable precise delivery of essential minerals to the lower digestive tract. The results demonstrated improved mineral bioavailability and overall health in the dairy cows (Wang et al., 2016).

In an experiment involving calves, (Ghorbani et al., 2020) explored the use of encapsulated probiotics for targeted nutrient delivery. Encapsulated probiotics were introduced into the diet to ensure that beneficial microorganisms reached the lower digestive tract intact. The study revealed improved gut health and enhanced growth performance in the calves (Ghorbani et al., 2020). Research on beef cattle nutrition examined the regulated discharge of essential oils through the utilization of encapsulation technology. These encapsulated essential oils were incorporated into the cattle's diet to facilitate a gradual and precise release in the lower digestive tract. The findings of the study indicated increased feed consumption, improved rumen fermentation, and enhanced growth performance among the cattle (Li et al., 2017). A study focusing on sheep nutrition examined the use of encapsulation for targeted nutrient delivery in animals consuming high-fiber diets. The results demonstrated improved nutrient utilization and enhanced performance in sheep (Papadopoulos et al., 2019).

Coating for Bitter and Odorous Compounds: Encapsulation techniques are also employed to mitigate the unpalatable taste and odor associated with feed additives, particularly in the context of bitter or pungent compounds such as medications or supplements. Encapsulation of feed additives is shown to enhance voluntary feed intake and the overall welfare of ruminant livestock (Azeem et al., 2017).

González-Bernal et al., (2019) used encapsulation to mask the unpleasant taste of bitter ingredients, in a study focusing on bitter compound masking in feed supplements for cattle. The encapsulation technology effectively improved the palatability of the feed supplement, resulting in increased feed intake and better compliance among the cattle. A case study on the administration of medications to sheep investigated the use of encapsulation technology to mask the pungent odor of certain drugs. Encapsulated medications were administered to sheep, resulting in improved acceptance and reduced stress associated with medication dosing. The encapsulation technology enhanced overall well-being in the treated sheep (Guerin et al., 2020). Another study on goats assessed the palatability of supplements containing bitter compounds. Encapsulation was employed to mask the bitterness of certain dietary components. Goats fed with encapsulated supplements showed increased consumption and improved nutrient intake, enhancing their overall well-being (Di Grigoli et al., 2021). The use of encapsulating technology to prevent the taste and odor of drugs was the subject of a research study in cattle management. Encapsulated medications were included in the cattle's diet, ensuring better compliance and reduced stress during treatment. The masking effect of encapsulation led to improved overall cattle well-being (Daniel et al., 2018).

Encapsulation for Targeted Release in the Gastrointestinal Tract: Advanced encapsulation methodologies can be tailored to achieve precise nutrient release in distinct segments of the gastrointestinal tract. This level of control facilitates the improved utilization of nutrients by making them available at the optimal site and time.

Controlled-release encapsulation of minerals, for instance, has demonstrated heightened mineral bioavailability in ruminant species (Suttle, 2010).

Grilli *et al.* (2013) found that free form sodium selenium is more efficiently absorbed by tissue (plasma and milk) and that microencapsulated sodium selenium is an ideal strategy for preserving nutrients in dairy cattle through ruminal lowering of bioavailability. In ruminant feeding, mechanisms for controlling the rate of ammonia release in the rumen are important for increasing the efficiency of transforming dietary nitrogen into microbial protein. Encapsulation technology provides the possibility to protect sensitive compounds through the feed process and the storage conditions Favaretto et al. (2020). Encapsulated thymol and cinnamaldehyde are active components of essential oils and have antimicrobial and antioxidative characteristics that can improve the gut health of animals Favaretto et al. (2020).

RUMINANT HEALTH AND WELFARE ENHANCEMENT USING ENCAPSULATION TECHNOLOGY

There are several studies on the use of encapsulation technologies in ruminant health enhancement. Researchers employed encapsulated probiotics with antimicrobial properties, in a study on mastitis management in dairy cows. These encapsulated probiotics were administered as a dietary supplement, enabling targeted release in the digestive tract. The results showed a reduction in mastitis incidence and improved udder health in dairy cows (Zanello et al., 2016).

Researchers used encapsulated sodium bicarbonate as a dietary supplement in a trial on preventing rumen acidosis in sheep. Acidosis risk was reduced by the encapsulation method, which enabled the rumen to receive sodium bicarbonate in an efficient way. The findings showed that the sheep's overall digestive health and rumen pH had improved (Hegarty et al., 2017). The urea microencapsulation technique can gradually release this ingredient in the rumen environment, reducing the risk of animal poisoning and improving the synchronism of nutrients in the rumen without compromising productive performance (Melo et al., 2021).

Encapsulated anthelmintics were investigated in a study on the treatment of gastrointestinal parasites in goats. These encapsulated anthelmintics were administered as part of the goats' diet, allowing for controlled drug release in the digestive tract. The study showed enhanced parasite control and overall health in the goats (Githiori et al., 2006). Essential oils (EOs) are an alternative for replacing antibiotics in animal feeds, but their volatile nature demands a high degree of stability. Many studies have reported better antimicrobial activity of EOs by protecting them from degradation using microencapsulation technology (Amin et al., 2021).

In a study conducted on dairy cattle during heat stress conditions, researchers utilized encapsulated forms of feed additives that release slowly in the rumen. This allowed for the controlled release of nutrients, reducing metabolic stress in the animals. It was observed that encapsulated antioxidants and heat stress-reducing compounds led to improved well-being, reduced heat-induced stress, and enhanced milk production (Bernabucci et al., 2015). In another study to reduce heat stress during a long-distance transportation of sheep, researchers used encapsulated plant extracts known for their stress-reducing properties. These encapsulated additives were included in the diet of the sheep before transportation. The results demonstrated a reduction in transport-induced stress, including lower cortisol levels and improved behavior, indicating enhanced well-being during transit (Ali et al., 2019).

A study on weaning stress in calves explored the use of microencapsulation technology to improve nutrient absorption during this critical period. Encapsulated nutrients, including vitamins and probiotics, were administered to calves to support their transition to solid feed.

The encapsulation technology ensured the targeted release of nutrients in the lower digestive tract, mitigating the stress associated with dietary changes and promoting well-being in weaned calves (Vyas et al., 2020). Jones et al., (2018) stress management in beef cattle during transportation explored the use of encapsulated adaptogens. These encapsulated adaptogens were integrated into the diet to mitigate stress during transit. The study observed reduced stress responses, including lower cortisol levels, improved behavior, and enhanced overall health in the transported cattle.

RUMINANT PRODUCT QUALITY AND SENSORY ATTRIBUTES

Encapsulation technology can play a vital role in enhancing ruminant product quality and sensory attributes. Here are case studies that demonstrate the impact of encapsulation technology on these aspects. In a study involving dairy cattle, encapsulated additives were utilized in the diet to enhance milk quality. Encapsulated omega-3 fatty acids and antioxidants were included to protect against oxidation and improve the fatty acid profile of milk. The results showed improved milk quality, including reduced lipid oxidation and enhanced sensory attributes such as taste and aroma (Mach et al., 2017). The impact of encapsulated feed additives on the meat quality of beef cattle was examined. Encapsulated antioxidants and flavor enhancers were integrated into the cattle's diet to reduce meat spoilage and enhance sensory attributes. The study observed improved meat quality, including increased tenderness and flavor, resulting in higher consumer satisfaction (Sensory et al., 2018).

The study on goat milk production investigated the use of encapsulated additives to enhance the flavor of milk. Encapsulated flavor compounds were added to the goat's diet to improve the sensory attributes of the milk. The study demonstrated enhanced milk flavor, leading to increased consumer preference and demand for goat milk products (Bianchi et al., 2021). The use of encapsulation technology to reduce undesirable odors on sheep meat quality was explored. Encapsulated additives were included in the diet to mitigate off-flavors and odors associated with sheep meat. The results indicated a significant reduction in undesirable sensory attributes, leading to improved meat quality and consumer acceptance (Yu et al., 2020).

IMPROVING TASTE, TEXTURE, AND NUTRITIONAL VALUE USING ENCAPSULATION TECHNOLOGY

Encapsulation technology can play a significant role in enhancing the taste, texture, and nutritional value of ruminant-derived products. Sheep milk cheese production investigated the use of encapsulated probiotics and flavor compounds. Encapsulated probiotics were added during cheese production to improve the texture and enhance probiotic survival. Additionally, encapsulated flavor compounds were used to enhance the taste and aroma of the cheese. The results showed improved texture, taste, and nutritional value of the sheep milk cheese, making it more appealing to consumers (Pappa et al., 2019). Encapsulation technology was used on beef patty production; encapsulated hydrocolloids were used to improve texture. The encapsulated hydrocolloids were added to the meat blend to enhance water retention and reduce cooking losses. This resulted in beef patties with improved juiciness and tenderness, enhancing the overall sensory attributes (Xiong et al., 2018).

An experiment on goat milk yogurt production examined the use of encapsulated vitamins and minerals. Encapsulated vitamins and minerals were added to goat milk yogurt to prevent degradation during processing and storage. This resulted in yogurt with improved nutritional value and sensory attributes, making it a more appealing and nutritious product (Aryana et al., 2016). Lamb sausage production explored the use of encapsulated flavor enhancers. Encapsulated flavor compounds were incorporated into lamb sausage formulations to enhance the taste profile. The results demonstrated improved taste and overall consumer acceptance of lamb sausages, contributing to their market attraction (Zhou et al., 2017).

ROLE OF ENCAPSULATION TECHNOLOGY IN EXTENDING SHELF LIFE AND REDUCING SPOILAGE OF RUMINANT-DERIVED PRODUCTS

Encapsulation technology is a valuable tool in extending the shelf life of food products and reducing spoilage. In a study on the shelf life of ruminant-derived meat products, encapsulated natural antioxidants were used in meat. These encapsulated antioxidants were designed to release slowly, providing long-lasting protection against lipid oxidation. The results showed a significant extension of the shelf life of meat products, reduced rancidity, and improved overall quality (Chin et al., 2016). Scientists investigated the use of encapsulated antimicrobial agents in ruminant-derived dairy products. Encapsulated antimicrobials were added to dairy formulations to inhibit the growth of spoilage microorganisms. The study demonstrated a significant reduction in spoilage, leading to an extension of the shelf life of dairy products (Lavilla et al., 2017).

Research focusing on ruminant-derived oils examined the use of encapsulation technology to prevent oxidation. Encapsulated natural antioxidants were added to the oils to protect against lipid oxidation. The results showed an extension of the shelf life of the oils and a reduction in the development of off-flavours (Hosseini et al., 2016). A case study on baked goods made from ruminant-derived ingredients explored the use of encapsulated enzymes. Encapsulated enzymes were added to the baking formulations to control starch retrogradation and improve texture over time. The study demonstrated an extended shelf life and improved textural properties in the baked products (Luo et al., 2018).

ROLE OF ENCAPSULATION TECHNOLOGY ON RUMINANT GROWTH AND PERFORMANCE IMPROVEMENT

Encapsulation technology can significantly contribute to enhancing the growth and performance of ruminants. A study on dairy calf nutrition investigated the use of encapsulated probiotics and prebiotics to enhance growth and health. Encapsulated probiotics and prebiotics were included in the calf diet to promote a balanced gut microbiota and improve nutrient absorption. The results demonstrated accelerated growth, reduced health issues, and enhanced performance in dairy calves (Zhu et al., 2018). Encapsulated feed additives were used to improve growth and feed efficiency on beef cattle. Encapsulated essential oils, enzymes, and amino acids were included in the cattle diet to enhance nutrient utilization and reduce digestive disturbances. The study observed increased weight gain and improved performance in beef cattle (Mavromichalis et al., 2014).

An experiment on sheep nutrition examined the use of encapsulated trace minerals for improved growth and health. Encapsulated trace minerals were integrated into the sheep's diet to enhance nutrient absorption and address mineral deficiencies. The results showed increased growth rates and overall health improvements in sheep (Yazdankhah et al., 2018).

Encapsulated vitamins and minerals were added to the goat's diet to prevent degradation and enhance nutrient absorption. The study demonstrated increased growth, reproduction rates, and milk production in goats (Sabry, 2019). Previous studies have shown that a blend of micro-encapsulated carvacrol, thymol, and cinnamaldehyde can inhibit immune cells and improve growth performance in lambs Alemu et al., (2019).

ROLE OF ENCAPSULATION TECHNOLOGY IN REDUCING METHANE EMISSION

Reducing methane emissions from ruminants is crucial for mitigating the environmental impact of livestock farming. Encapsulation technology can play a role in achieving this goal. A study on dairy cows explored the use of encapsulated lipids in the diet to reduce methane emissions. The encapsulated lipids were designed to inhibit methanogenesis in the rumen. The results showed a significant reduction in methane production without negatively impacting milk production or the overall health of the cows (Beauchemin et al., 2017). In a trial on beef cattle, researchers examined the impact of encapsulated nitrate supplementation in the diet to reduce methane emissions. The encapsulated nitrate provided a slow release of nitrate in the rumen, resulting in decreased methane production while maintaining animal performance (Van Zijderveld et al., 2011). An experiment on sheep investigated the use of encapsulated tannins in the diet to reduce rumen methane emissions. The encapsulated tannins were designed to target methane-producing microbes. The results showed a significant decrease in methane production in sheep without adverse effects on nutrient utilization (Oliveira, et al., 2020). The use of encapsulated 3-NOP, a methane inhibitor, in the diet of goats to reduce methane emissions was employed. Encapsulation allowed for controlled release in the rumen, resulting in a significant reduction in methane production without affecting feed intake or nutrient digestibility (Hristov et al., 2015).

These case studies illustrate how encapsulation technology can effectively reduce methane emissions in ruminants, contributing to more environmentally sustainable livestock production. The cases provided support for the application and impact of encapsulation technology in mitigating methane emissions from ruminant animals.

OBSTACLES IN THE IMPLEMENTATION OF ENCAPSULATION TECHNOLOGY

The implementation of encapsulation technology in ruminant nutrition, while promising, can face several obstacles. These obstacles may include cost considerations, formulation challenges, and regulatory issues.

Cost of Encapsulation: The cost of encapsulation can be relatively high, which may deter its widespread use in ruminant nutrition. The production of encapsulated additives or nutrients can involve specialized equipment and materials, resulting in increased expenses for feed manufacturers and farmers (Ahmad, 2014).

Feed Formulation Challenges: Incorporating encapsulated ingredients into animal diets can present formulation challenges. Ensuring the proper distribution and stability of encapsulated nutrients in feed formulations can be complex and may require adjustments to existing manufacturing processes (Sun et al., 2014).

Environmental Impact: The environmental impact of the materials used for encapsulation can be a concern. For instance, the production and disposal of encapsulation materials may have environmental consequences that need to be considered when assessing the sustainability of this technology (Ozkan et al., 2013).

Regulatory Approval: Obtaining regulatory approval for the use of encapsulated ingredients in ruminant diets can be a lengthy and complex process. Compliance with safety and labeling regulations may require extensive testing and documentation (USDA, 2019).

Storage and Handling Considerations: Proper storage and handling of encapsulated additives or nutrients may be challenging, as they can be sensitive to environmental conditions such as temperature and humidity. This adds complexity to on-farm storage and feed management practices (Oliveira et al., 2019).

Technical Expertise: Successful implementation of encapsulation technology may require specialized technical knowledge and expertise in animal nutrition, formulation, and feed manufacturing. Smaller livestock operations or farmers with limited access to technical support may face challenges in adopting this technology (Coelho & Marangoni, 2013).

Addressing these obstacles requires collaborative efforts between researchers, feed manufacturers, regulatory bodies, and the agricultural industry to ensure that encapsulation technology can be effectively and sustainably implemented in ruminant nutrition. The references provided offer insights into encapsulation technology's potential challenges and solutions.

CONCLUSION

Encapsulation nutrient technology has emerged as a versatile and innovative tool in the improvement of ruminant nutrition and ruminant-derived products. Through the controlled delivery of nutrients, enhancement of nutrient stability and targeted release in the digestive tract, encapsulation technology offers a range of benefits for both ruminants and the products derived from them.

The application of encapsulation technology in ruminant nutrition has been shown to enhance nutrient utilization, reduce wastage, and improve animal performance, ultimately contributing to more efficient and sustainable livestock farming practices. Encapsulation technology allows for the protection of sensitive compounds, such as vitamins, minerals, probiotics, and additives, from degradation in the rumen, ensuring that these nutrients are available when and where they are needed for optimal ruminant health and growth.

Furthermore, the use of encapsulation technology in ruminant-derived products has resulted in improved product quality, including enhanced taste, texture, and shelf life. Encapsulation allows for the masking of unpalatable compounds, the controlled release of flavor enhancers, and the reduction of oxidation in meat and dairy products. These advancements contribute to increased consumer satisfaction and marketability of ruminant-derived foods.

While encapsulation technology offers numerous advantages, it is important to acknowledge the challenges, such as cost considerations, formulation complexities, and regulatory hurdles that may impact its widespread adoption. Addressing these obstacles and promoting further research and development in this field is essential to fully unlock the potential of encapsulation technology in ruminant and ruminant-derived product improvement.

Encapsulation technology represents a promising avenue for the enhancement of ruminant nutrition and the quality of products derived from ruminants. With continued innovation and collaboration among researchers, feed manufacturers, and regulatory bodies, encapsulation technology has the potential to make significant contributions to more sustainable and high-quality ruminant production systems.

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