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Use of additives and secondary compounds in goats and sheep nutrition: Literature review

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ABSTRACT

With the prohibition of the use of antibiotics in animal production as growth promoters due to side effects and the presence of residues in animal-derived products, there is a need for the development and use of alternative substances to replace antibiotics. Feed additives and secondary compounds derived from plant extracts have been used in animal feed as substitutes for antibiotics, performing therapeutic and prophylactic functions. The aim of this review is to present a comprehensive summary on the use of additives and secondary compounds in the nutrition of small ruminants, highlighting their role as effective nutritional strategies for improving performance and animal health, as well as the challenges in developing sustainable, safe, and affordable alternatives. However, the effectiveness of feed additives in animal nutrition depends on multiple factors, such as the type of diet, the physiological stage, and the animal category, as well as management conditions. Thus, the selection and proper use of additives should be based on scientific evidence and adjusted to the particularities of each system, always aiming for a balance between productivity, animal welfare, and environmental responsibility.

RESUMO

Com o impedimento do uso dos antibióticos na produção animal como promotores de crescimento devido aos efeitos colaterais e à presença de resíduos em produtos de origem animal, existe uma necessidade para o desenvolvimento e a utilização de substâncias alternativas para a substituição dos antibióticos. Os aditivos alimentares e compostos secundários provenientes de extratos de plantas têm sido utilizados na ração animal como substituintes dos antibióticos, exercendo funções terapêuticas e profiláticas. O objetivo desta revisão é apresentar um resumo abrangente sobre o uso de aditivos e compostos secundários na nutrição de pequenos ruminantes, destacando seu papel como estratégias nutricionais eficazes para a melhoria do desempenho e da saúde animal, além dos desafios no desenvolvimento de alternativas sustentáveis, seguras e acessíveis. Contudo, a eficácia dos aditivos na alimentação animal, depende de múltiplos fatores, como o tipo de dieta, o estágio fisiológico e a categoria animal, além das condições de manejo. Assim, a escolha e o uso adequado dos aditivos devem ser baseados em evidências científicas e ajustados às particularidades de cada sistema, visando sempre o equilíbrio entre produtividade, bem-estar animal e responsabilidade ambiental.

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Introduction

Nutrition represents one of the determining factors of the productive performance of small ruminants, directly influencing the quality of animal-origin products. In this context, traditional additives such as ionophores, antibiotics, and growth promoters, although effective, have been questioned due to regulatory restrictions and consumer concern about residues in food, which can lead to the transfer of resistant bacteria and their resistance factors from animals to humans (Cheng *et al*., 2014; Ghimpeteanu *et al*., 2022). Due to these concerns, in 2006, the member countries of the European Union (EU), through the Regulation of the European Parliament and of the Council (EC) no. 1831/2003, prohibited the use of all antibiotic growth promoters in animal production (Ivanova *et al*., 2024).

In view of this, the search for alternatives to replace growth-promoting antibiotics has intensified, opening the way for the investigation of natural alternatives that increase feed efficiency, reduce losses (nitrogen, energy), and improve herd health (Pandey *et al*., 2019; Vieira *et al*., 2020; Ivanova *et al*., 2024), highlighting plant secondary compounds. Many of these compounds exert effects on the ruminal microbiota and, consequently, on digestibility, ruminal proteolysis, and short-chain fatty acid fermentation (Patra and Saxena, 2010). In small ruminants, such as goats and sheep, maintaining ruminal health is essential to ensure high levels of production with lower environmental impact, making it a promising strategy to contribute to the quality of final products and mitigate greenhouse gas emissions (Raheem *et al*., 2024; Wang *et al*., 2024; Li *et al*., 2025).

The study on the use of additives and secondary compounds in the nutrition of small ruminants is part of a context of innovation, sustainability, and competitiveness. Experimental trials with the use of additives derived from plant extracts in animal nutrition have been expanding globally, aiming to obtain information on the potential toxic effect of such an ingredient and the animal response related to diet acceptability, performance, and efficiency in feed utilization (Raheem *et al*., 2024). Furthermore, the use of natural alternatives that are easy to handle and low cost is sought (Wang *et al*., 2024; Rashwan *et al*., 2025), and feed resources obtained from regional raw materials or agro-industrial residues can be used, adding value to local production chains (Oliveira *et al*., 2020; Danieli and Schogor, 2020).

In view of the above, the aim was to carry out a survey on the use of additives and secondary compounds in the nutrition of small ruminants, highlighting their role as effective nutritional strategies for improving performance, animal health, and sustainability in goat and sheep production.

Zootechnical additives used in ruminant nutrition

According to the Ministry of Agriculture, Livestock and Supply (MAPA, 2004), in the normative instruction IN 13/2004, zootechnical additives are defined as a substance, microorganism, or formulated product, intentionally added to products, which is not normally used as an ingredient, whether or not it has nutritional value, and that improves the characteristics of products intended for animal feed or animal products, improves the performance of healthy animals, or meets nutritional needs.

Zootechnical additives are classified into three groups: digestive, microbiota balancers, and performance enhancers. These compounds act by modulating the gastrointestinal environment, removing harmful microorganisms, and altering the microbial population, promoting a more favorable balance between beneficial and harmful microorganisms (Kholif *et al.*, 2023). Danieli and Schogor (2020) report that additives can be substances of natural or synthetic origin, which are added to food in the amount strictly necessary to achieve the desired effect.

In goats and sheep, for example, additives such as vegetable oils, protective extracts (tannins), and probiotics show potential in stabilizing ruminal fermentation, promoting better nutrient digestion and energy utilization. In these species, the use of zootechnical additives helps to contain excessive production of ruminal acids, reduce methane losses, and optimize microbial protein production, contributing to better productive performance and animal health (Assis, 2019).

Secondary plant compounds

Plants produce significant amounts of secondary metabolites that act as defense mechanisms against herbivores and as chemical barriers in competition with other plants and microorganisms. These compounds can be classified into three main groups: terpenes, phenolic compounds, and alkaloids, which vary according to their biosynthetic pathway and chemical structure (Baungratz *et al.*, 2024). Among these compounds, terpenes occur in various forms, including terpenoids, monoterpenes, sesquiterpenes, diterpenes, and triterpenes. Triterpenes (C30) are particularly important, being widely distributed in the plant kingdom and extensively used in pharmacology. In this category, steroids, triterpenic or steroidal saponins, and cardiac glycosides stand out as the most relevant compounds (Bodas *et al.*, 2012).

Structurally, saponins are composed of 27 carbon atoms, presenting three main classes: Steroids, glycosylated triterpenoids, and steroidal alkaloids (Wina *et al.*, 2005). These compounds have the ability to interact with the sterols present in cell membranes, inducing structural modifications that result in increased membrane permeability, facilitating the entry of ions and water molecules into the cell interior, eventually leading to rupture (Karabailiev and Kochev, 2003). De Souza *et al.* (2016) report that saponins are particularly effective in inhibiting rumen ciliate protozoa. They contribute significantly to improved protein synthesis, since they reduce bacterial predation by protozoa, consequently increasing the duodenal flow of proteins.

The selective removal of protozoa in the rumen demonstrates potential to increase the ruminal bacterial population by up to four times, highlighting the ability of saponins to optimize microbial protein synthesis (Newbold and Hillman, 1990). At the same time, plant compounds containing saponins have been shown to be effective in reducing enteric methane emissions, particularly through their modulatory action on the protozoa population (Wanapat *et al.*, 2013).

Kholif (2023) reports that saponins have an antiprotozoal effect, potentially inhibiting methanogenesis by reducing the activities of ruminal methanogens. The author also reports that saponins affect ammonia adsorption and modulate ruminal passage of digesta, causing changes in ruminal metabolism, and that their use to overcome problems associated with inefficient N retention and utilization in ruminants can be recommended.

However, research points to significant limitations in the use of these compounds, since the ruminal microbiota shows adaptive capacity to saponins (Ivan *et al.*, 2004), in addition to altering its fermentative profile in response to different dietary levels of these compounds (Wina *et al.*, 2005). One of the factors that influences the benefits of saponin administration is the identification of the main bioactive saponins that can specifically inhibit protozoa and methanogens. The adaptability of ruminal microorganisms to saponins after long-term use is an issue that requires further evaluation (Kholif, 2023).

The dose-dependent effect of saponins represents a particular challenge, as high concentrations can compromise animal performance (Li and Powers, 2012), highlighting the need for precise dosages in dietary formulations. Wang *et al.* (2009), when providing 170 mg/day to sheep, observed that saponin had the potential to reduce ruminal methane production, which was associated with lower N-NH3 and higher concentrations of short-chain fatty acids in the rumen of the sheep. Hess *et al.* (2004) when offering sheep a diet containing crude saponins at a dose of 0.6 g/kg of metabolic weight ($PM^{0,75}$), observed that saponins did not decrease the concentration of ammonia in the ruminal fluid, but the concentration of ureic N in the blood and urinary N excretion decreased, suggesting that less ammonia was absorbed from the rumen. The authors report that the sharp decline in the proportion of urinary N relative to total excreted N is of environmental relevance, since urinary N is prone to ammonia emission.

Tannins are water-soluble phenolic compounds that occur in the form of esters or heterosides in nature (Fotso *et al.*, 2025) and represent the fourth most abundant group of secondary compounds in plant vascular tissue (Adamczyk *et al.*, 2017), acting in protection against fungi, bacteria, viruses, and herbivores due to potential toxic effects (Gelgelo *et al.*, 2024). They have a molecular weight between 500 and 3000 Daltons, possessing the ability to form water-insoluble complexes with proteins, gelatins, and alkaloids (Jung *et al.*, 2021), with the ability to form complexes with proteins being a unique feature of tannins (Adamczyk *et al.*, 2017).

They are divided into two main groups: hydrolyzable tannins (HT) and condensed tannins (CT). The distinction between the two groups is based on chemical aspects, such as resistance to hydrolysis and chemical stability. Hydrolyzable tannins are hydrolyzed by acids, bases, or enzymes into glucose and ellagic acid or into glucose and gallic acid (Soldado *et al.*, 2021; Marrone *et al.*, 2024). Condensed tannins (procyanidins and prodelphinidins) are oligomers or polymers formed by flavan-3-ol units, such as catechin, epicatechin, gallocatechin, and epigallocatechin. Their depolymerization occurs only under oxidative hydrolysis conditions or under the action of strong acids, being resistant to enzymatic degradation in anaerobic environments (Weng *et al.,* 2021).

Terra-Braga *et al.* (2024), investigating the effects of ingesting a blend of condensed and hydrolyzable tannins (a mixture composed of $^1/_3$ chestnut tannin extract and $^2/_3$ quebracho tannin extract, totaling 4% on a dry matter basis) in growing lambs, observed that the lambs adjusted their total feed intake as the tannin extract was added, showing increasing levels of dry matter intake as the tannin concentration increased. The authors concluded that the tannin blend did not limit average daily gain but induced changes in nitrogen excretion, contributing to the reduction of environmental pollutants such as ammonia, nitrous oxide, and nitrates.

Generalizations about the antinutritional effects of CT in animals are still observed, such as the reduction of diet palatability, with a consequent decrease in dry matter intake and nutrient digestibility (Naumann *et al.*, 2017). In addition, tannins have an astringent taste due to the tannin-protein complexes formed from saliva proteins; thus, the higher the protein bound by CT, the greater the astringency and the lower the palatability, as reported by Naumann *et al.* (2017), which may limit consumption.

However, Silva *et al.* (2021), when offering diets with (5% on a dry matter basis) and without condensed tannins for lactating goats, observed that dry matter intake was similar between the tested diets. The authors expected changes in nitrogen and energy balance due to the inclusion of tannin in the diet, which did not occur because of the dietary tannin adaptation mechanisms developed by the goats, since the animals had 25 days of adaptation to the diets. This fact was justified by Schmitt *et al.* (2020), who emphasize that during feeding, goats secrete a greater amount of saliva containing proline-rich salivary proteins (PRP). The PRP binds to tannin, preventing its complexation with dietary protein, and this process increases the ruminal degradability of feed protein, enhances microbial protein synthesis, and the supply of nitrogen to the small intestine, consequently increasing the absorption of amino acids for production.

Antioxidant properties are considered one of the main benefits of including tannins in animal feed, improving welfare and performance. Soldado *et al.* (2021) reported that the inclusion of condensed tannins (CT) and plant extracts in ruminant diets can improve the antioxidant status of animals and consequently improve the oxidative stability of animal-derived products. Evaluating supplementation with different levels of tannins (0, 0.3%, and 0.6%) from chestnut on meat quality and antioxidant capacity in Hu lambs, Wang *et al.* (2023) found that the use of 0.3% chestnut tannins reduced the malondialdehyde content in lamb meat, which increased the shelf life of the meat by 8.7 hours. The authors emphasize that, based on transcriptomic results, supplementation with 0.3% chestnut tannins can improve meat quality and the antioxidant capacity of Hu lambs by increasing the expression of the antioxidant enzyme gene.

Guerreiro *et al.* (2020), investigating the inclusion of the aerial part and the condensed tannin extract (0, 1.25, and 2.5%) of *Cistus ladanifer* L. in diets for lambs on growth performance, carcass and meat quality, and fatty acid composition of intramuscular and subcutaneous fat, concluded that the inclusion of 1.25% *C. ladanifer* CT extract in the diet increased the deposition of t11–18:1 in intramuscular and subcutaneous fat, but did not affect performance and meat quality. The authors conclude that *C. ladanifer* CT extract can be used as a natural additive in ruminant diets as a tool to induce beneficial changes in the ruminal biohydrogenation pattern and, consequently, in the fatty acid profile of fat.

The effects vary according to the chemical structure and concentration of CT in the diets, the composition of the basal diet, the presence of pro- and antioxidant compounds, or other uncontrolled factors that can create a different balance between antioxidant and pro-oxidant agents. In different studies (Table 1), the effects of condensed tannins or their extracts on CH4 production in the rumen and on fermentation parameters are reported. Furthermore, high concentrations of CT decrease volatile fatty acid concentrations in the rumen, as the size of the ruminal pool tends to increase due to the slower digestion rate. This reduction in the digestion rate can slow the elimination of feed residues from the rumen, increase the need for rumination, and thus reduce voluntary feed intake (Min *et al.,* 2005, Waghorn, 2008, Huang *et al.*, 2023, Fonseca *et al.,* 2024).

Table 1:

Effect of tannins or their extracts on CH4 production in the rumen and on fermentation parameters.

Source of tannin	Species	Level of inclusion	Type of food	CH_4 (%) reduction	Effect of ruminal fermentation parameters
[a]*Acácia mearnsii*	Ovine	41g/kg of a diet (extract)	Mixture of ryegrass and alfalfa (1:1)	9.90%	Digestibility, short-chain fatty acids, and total number of protozoa were not affected, it reduced the ratio Ca:P.
[b]*Lespedeza striata*	Goats	33-100%	Sudan grass	32.9- 58.4%	Reduction in digestibility and number of protozoa; SCFA and Calcium:Phosphorus were not affected.
[c]*Lespedeza cuneata*	Goats	Exclusive diet	*L. cuneata*	51.4	Reduction in digestibility and in the number of protozoa; SCFA and Ca:P ratio were not affected.
[d]*Lespedeza cuneata*	Ovine	100% of the forage	*Lespedeza* hay	Not significant	Reduction of M.O, N and FDN.
[d]*Lespedeza cuneata*	Goats	100% of the forage	*Lespedeza* hay	Not significant	Reduction of FDN, M.O and N.
[e]Extratos vegetais (casca, raiz e sementes)	Goats	0-40 g kg^{-1} of a diet	Basal diet + plant extracts	Linear reduction	Increase in total SCFA and propionate; Reduction in NH_3-N and acetate:propionate.
[f]Fonte comercial	Ovine	30–50 g/kg MS	Grass hay + pellet-based diet	51–60	Reduction of NH_3-N; did not change digestibility and increased propionate.
[g]*Sericea lespedeza*	Ovine and goats	Exclusive diet	Hay of *S. lespedeza*	Not evaluated	Modulation of fibrolitic bacteria and propionate; reduction of protozoa and methanogenic microorganisms.
[h]*Sericea lespedeza*	Ovine	90, 180, 270 g/kg of a diet	Alfalfa silage + silage of *S. lespedeza*	Not evaluated	Reduction in digestibility of DM, OM, fiber and NH_3-N; modulation of fermentation; changes in nitrogen balance.
[i]*Lespedeza striata*	Goats	33–100% of a diet	Sorgo-sudão	32.9–58.4	Reduction in digestibility and the number of protozoa; SCFA and Ca:P ratio were not affected.

Source: Prepared by the authors, based on [a] Carulla *et al.* (2005), [b] Min *et al.* (2005), [c] Animut *et al.* (2008), [d] Min *et al.* (2005), [e] Shilwant *et al.* (2023), [f] Ng'ambi *et al.* (2022), [g] Min *et al.* (2024), [h] Niyigena *et al.* (2024), [i] Wang *et al.* (2022).

Probiotics and yeasts

According to the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO/WHO, 2002), probiotics are defined as "live microorganisms that, when administered in adequate amounts, confer a health benefit on the host." They are mainly viable and non-pathogenic organisms, and their supplementation benefits the host's health by competing with other pathogenic microbes (Uyeno *et al.,* 2015).

The proper balance of ruminal microbes is essential for maintaining animal health and effective food digestion (Adjei-Fremah *et al.*, 2018). Bąkowski and Kiczorowska (2021) infer that probiotics can manipulate the rumen microbial ecosystem, digestibility, and degradability of food when administered in adequate amounts, ranging from 1 g/day to 10 g/day for goats and sheep. In addition, the use of probiotics can increase the bioavailability of microorganisms and digestive capacity, reduce ruminal pH and lactate levels. Furthermore, they play a critical role in enhancing mucosal immunity by activating and stimulating immune cells, preventing enteric pathogens from colonizing the intestine, and improving nutrient utilization and absorption (Hutkins *et al.,* 2016).

The main microorganisms used as probiotics in ruminant feed are: *Streptococcus*, *Bacillus*, *Lactobacillus*, *Enterococcus*, *Propionibacterium*, *Bifidobacterium* and *Prevotella bryantii* and fungal species such as: *Saccharomyces* and *Aspergillus* (Kulkarni *et al.,* 2022). The action of these microorganisms as probiotics is based on the modulation of the immune system, attenuating virulence markers of certain pathogens, preventing infectious and inflammatory diseases, as well as serving as a biological control agent in the prevention of spoilage, and they can be classified as lactic acid-utilizing bacteria or lactic acid-producing bacteria (Kulkarni *et al.,* 2022).

Among the listed probiotics, the most prominent used for ruminants and monogastrics are yeasts of the genus *Saccharomyces cerevisiae* and fungal strains (*Aspergillus oryzae*) (Varada *et al.*, 2024). Yeasts are composed of a mixture of yeast biomass and fermentation metabolites (alcohols, esters, organic acids, among others) (Shurson, 2018; Mahesh *et al.*, 2021). Mahesh *et al.* (2021) report that dry brewer's yeast, torula (*Candida utilis*), and whey yeast are also used in animal feed (Mahesh *et al.,* 2021).

Due to the effects of synergistic adhesion, combinations of various probiotic strains can enhance health benefits compared to individual strains (Elghandour *et al.*, 2015). In Sanjabi sheep supplemented with a commercial multi-strain probiotic mixture (*Lactobacillus acidophilus, Lactobacillus casei, Bifidobacterium thermophilum and Enterococcus faecium*) during the last third of the lactation period, they showed an increase in milk production and its components (Kafilzadeh *et al.*, 2019). Solimam *et al.* (2016) when feeding growing lambs with diets supplemented with probiotics (*Propionibacterium freudenreichii*, *Lactobacillus acidophilus*, *Lactobacillus casei*, *Enterococcus faecium*, *Lactobacillus lactis*, *Pediococcus cerevisiae*, *Megasphaeraelsdenii*, *Bacillus licheniformis* and *Aspergillusoryzae*) at the dose of 10 g/h/day, beneficial effects were observed on productive performance, digestibility coefficients, ruminal parameters, and economic efficiency.

Although some species, such as *Bacillus cereus,* may cause problems due to the endotoxins and emetic toxins they produce (Anadón *et al.*, 2006), bacteria of the genus *Bacillus* used as probiotics, they have real potential and can be used in safe production and as an alternative to antibiotics. Mousa *et al.* (2019), investigating the potential effects of *Bacillus subtilis* supplementation in Barki lambs on the immune system and the antioxidant properties on stress, found that the animals that received the supplementation showed an increase in the total number of leukocytes and lymphocytes, lysozyme activity, reduction of glutathione and total antioxidant capacity, with lower malondialdehyde values after 4 weeks of supplementation and higher levels of serum catalase and nitric oxide after 2 weeks of supplementation. The authors emphasize that *B. subtilis* can be a useful nutritional supplement for the immune system, promoting antioxidant capacity with maximum stimulation of the lambs' immune system.

Lactobacillus are Gram-positive bacteria that belong to the group of lactic acid-producing bacteria. This group is very large and heterogeneous and includes more than 100 different species (Nabgan *et al.*, 2025). Most species found in this group are part of the normal microbiota of mammals (Rachwał and Gustaw, 2024). In addition, some species are used as food additives, due to *Lactobacillus* strains producing active dietary enzymes, including protease, amylase, lipase, phytase, and protease, which act in the digestion and absorption of nutrients (Kim *et al.,* 2007).

Probiotics of the genus Bifidobacteria are found in large numbers in the rumen. Their presence in the intestine generally indicates the good health of the host (Gaggìa *et al.,* 2010). Saleem *et al.* (2024) report that bifidobacteria produce essential active compounds, such as vitamins and amino acids, and help in the development of lymphoid tissue. In their discussion, the authors emphasize that supplementation of lambs with *L. acidophilus* and a combination of *Bifidobacterium animalis* and *B. longum* improved immunoregulatory functions and humoral responses and demonstrated modulation of lipid metabolism and increased immune response in the host.

Prebiotics

Prebiotics are substrates that are selectively used by microorganisms in the gastrointestinal tract and that confer health benefits to the host (FAO/WHO, 2002; Markowiak e Ślizewska, 2017). They are mainly carbohydrates, peptides, proteins, and indigestible lipids that induce the activities of a healthy microbiota (such as *Lactobacillus* and *Bifidobacteria*) in the gastrointestinal tract and can be used in defense against pathogens and modulation of the immune system (Zhang *et al.*, 2021). In ruminants, prebiotics have shown positive effects on growth, feed efficiency, and host health. However, the effects of prebiotics in ruminants are still little explored (Cangiano *et al.,* 2020).

Mannanoligosaccharide (MOS) is the prebiotic that has the largest number of studies. It is one of the prebiotics extracted from the cell wall of yeasts that aims to help maintain digestive efficiency, the integrity of the intestinal epithelium, thus increasing nutrient absorption, and also stimulating the immune system (Cangiano *et al.,* 2020). Zhang *et al.* (2023) Researching the addition of MOS in sheep found that the diet significantly increased total protein levels, serum glucose, serum immunoglobulin G, total serum antioxidant capacity, and superoxide dismutase activity. Yang *et al.* (2022), in a study with neonatal goats supplemented with MOS (0.06% of body weight at birth) in colostrum and milk replacer, found that supplementation with MOS during the neonatal period increases antioxidant capacity and reduces inflammatory response, in addition to promoting immunoglobulin A secretion and colonization by *Firmicutes* and *Lactobacillus* in the ileum. Thus, the positive effects induced by MOS are more pronounced in neonatal goats, which may be an effective approach to maintain intestinal health and improve the survival rate of neonatal ruminants.

Fructooligosaccharides (FOS) have benefits that are similar to other prebiotics. The immunostimulant action is attributed to the promotion of lactic acid bacteria, which are: *Lactobacillus acidophilus, Bifidobacterium bifidum and Bifedobacterium longum* (Angelakis, 2017). These species of microorganisms have the ability to maintain a balanced gastrointestinal pH, preventing excessive acidification, and to block the growth of pathogenic bacteria, mainly through the mechanism of competitive exclusion (Sanders *et al.*, 2019). As is the case with bacteria of the genus *Bifidobacterium* that protects the host against enteropathogens by competing for nutrients and producing acetate (Hsieh *et al.,* 2015).

Galactooligosaccharides (GOS) are polymers of galactose with a terminal glucose monomer. This group of prebiotic is called β-GOS and have terminal β-linked glucose (Charalampopoulos & Rastall, 2009). They are produced by the transgalactosylation of lactose by the enzyme β-galactosidase from lactose-rich products. These stimulate the growth and development of the intestinal microflora (Cais-Sokolinska *et al.*, 2022).

Cangiano *et al.* (2020) the review "Strategic Use of Probiotics and Microbially-Based Prebiotics in Dairy Calf Rearing" reports that there is no robust evidence proving significant effects on the growth, health, or immune status of ruminants. Despite the lack of studies, in recent years metataxonomics has been a promising strategy that allows evaluating the symbiotic effect of prebiotics (Torres-Maravilla *et al.*, 2022). Therefore, more in-depth studies are needed to investigate the mechanisms of action of prebiotics and their impacts on the diversity and abundance of rumen microorganisms.

Bacteriocins

Bacteriocins constitute a heterogeneous group of antimicrobial peptides synthesized by bacteria (Cotter, 2013). This group of prebiotics stands out for its efficacy, low cytotoxicity, and for not promoting the transfer of resistance genes (Hoang *et al.*, 2011; Vieco-Saiz *et al.*, 2019). In goats, supplementation with commercial antimicrobial peptides positively altered the ruminal microbiota, increasing the relative abundance of *Fibrobacter*, *Anaerovibrio* and *Ophryoscolex* (Ren *et al.*, 2019).

The spectrum of action of bacteriocins is variable, and can cover specific microbial groups or phylogenetically distinct ones (Negash and Tsehai, 2020). The inhibition of the target pathogen occurs through interaction with phospholipids or receptors of the cytoplasmic membrane (Meade *et al.*, 2020). In addition to the antimicrobial action, *in vitro* studies indicate antitumor properties (Chumchalová and Šmarda, 2003), synergy with probiotics, acting as colonizing peptides and enhancing their attachment in the gastrointestinal tract (Yang *et al.*, 2014), and participation as signaling molecules in immune modulation (Van Hemert *et al.*, 2010).

Among lantibiotics, nisin (a small peptide composed of 34 amino acids), produced by *Lactococcus lactis*, is widely used in the food industry to control microorganisms that cause intoxication and to extend the shelf life of products (Deegan *et al.*, 2006). It has a mode of action similar to ionophores, showing antibacterial activity mainly against lactic bacteria and other Gram-positive bacteria (Santoso *et al.*, 2004). Other bacteriocins with technological potential include macedocin, synthesized by *Streptococcus macedonicus*, effective as a starter culture in fermented foods (Georgalaki *et al.*, 2002); warnericin RB4, from *Staphylococcus warneri* RB4, capable of suppressing spoilage microorganisms in juice-based beverages (Minamikawa *et al.*, 2005); and bovicin HC5, isolated from the bovine rumen, indicated for preserving fruit juices (De Carvalho *et al.*, 2008).

As an additive in ruminant diets, it has proven to be a promising alternative to conventional antibiotics by modulating the volatile fatty acid profile and reducing methanogenesis, as observed by Sar *et al.* (2005) in their *in vitro* study, where, as the nisin concentration increased from 5 to 30 μmol/L, methane production decreased by 14 to 40%, the acetate/propionate ratio decreased, and total volatile fatty acids increased, but it did not reduce nitrate toxicity when this was used to inhibit methane production.

Nisin, which acts directly on methanogens, may be more effective than other additives in reducing methane production, as reported by Santoso *et al.* (2004) when investigating the effect of nisin supplementation on ruminal methanogenesis, nitrogen, and energy metabolism in sheep. In this study, it was observed that natural products like nisin have the potential to be used as a ruminal fermentation manipulator, given that its action resulted in lower energy loss in the form of methane.

Chitosan

Chitosan is a polysaccharide obtained by the deacetylation of chitin from crustaceans and fungi, whose structure, similar to cellulose, gives it biocompatibility, low toxicity, and antimicrobial activity. These properties support the interest in its use as an alternative additive in ruminant nutrition, particularly to modulate ruminal fermentation (Şenel *et al.*, 2004), reducing methane emissions and contributing to lower energy loss and lower environmental impact (Belanche *et al.*, 2016), indicating better energy utilization (Goiri *et al.*, 2009).

In sheep, when evaluating the use of chitosans to modulate ruminal fermentation of a 50:50 forage-to-concentrate diet, Goiri *et al.* (2013) observed that the addition of chitosan decreased neutral detergent fiber digestibility and methane production and increased propionate proportions. The authors concluded that chitosan directed fermentation towards more energetically efficient pathways and that chitosan modifies the microbial ecosystem, negatively affecting cellulolytic bacteria and, thereby, modulating ruminal and cecal fermentative activity. In goats, El-Zaiat *et al.* (2025) found that supplementation with increasing doses of chitosan (0, 0.300, and 0.600 g/day) decreased ruminal pH, estimated methane production, ammoniacal nitrogen concentrations, and protozoa abundance. However, as the doses of chitosan in the diet were increased, there was an increase in ruminal propionate and improved fiber and protein digestion, without affecting feed intake, milk production, or composition.

These results, although dependent on the dose, the degree of deacetylation, and the composition of the diet, indicate that chitosan presents itself as a promising alternative to conventional antimicrobial additives, combining productive gains with the mitigation of environmental impacts.

Enzymatic additives

The supplementation with exogenous enzymes in the feeding of ruminants aims to optimize the digestibility of diet ingredients and improve nutrient utilization (Zilio *et al.*, 2019). In production systems where forages form the main part of the diet, the use of fibrolitic enzymes, such as xylanases and cellulases, proves effective in enhancing the degradation of the fibrous fraction, promoting greater efficiency in diet utilization (Chung *et al.*, 2012; Zilio *et al.*, 2019).

The response to enzyme supplementation is conditioned by variables such as diet composition, the type and specific activity of the enzymes, the form and timing of administration, the stability of the compounds in the ruminal environment, and the dosage used (Arriola *et al.*, 2017; Zilio *et al.*, 2019). Freitas *et al.* (2023a) when evaluating the effect of exogenous enzymes (Allzyme® (enzyme mix), Fibrozyme® (fibrinolytic enzyme) and Amaize® (amylolytic enzyme)) provided as an additive in feed for goats on productive and behavioral parameters and observed a reduction in intake and chewing and more time spent by the animals in idle. At another time, Freitas *et al.* (2023b), when investigating the blood metabolites of kids fed with exogenous enzymes in the diet, observed increases in the values of energy and protein metabolites due to greater degradation of food provided by the enzymes, generating more available energy for the animals.

In sheep, Neiva *et al.* (2022) evaluated the effect of adding exogenous enzymes (Allzyme® (enzyme complex), Fibrozyme® (fibrinolytic enzyme), Amaize® (amylolytic enzyme) and Mix (enzyme complex: 150g Allzyme® + 180g Fibrozyme® + 150g Amaize®) regarding the diet on intake, nutrient digestibility, nitrogen balance, ingestive behavior, and ruminal movement of sheep, they observed that the use of exogenous enzymes or exogenous enzyme complexes Amaize® and Allyzme® increases intake and nutrient digestibility, as well as nitrogen balance and chewing efficiency, without causing detrimental effects on ruminal physiology and ingestive behavior of lambs. Furthermore, the authors found that the addition of the enzymatic mixture does not improve intake and nutrient utilization by sheep.

Ionophores

Ionophores are widely used in the nutrition of ruminants with the aim of optimizing energy and protein metabolism, as well as reducing digestive disorders such as ruminal acidosis and bloat. Their action is based on the ability to suppress or inhibit gram-positive microorganisms, the main producers of lactic acid, thus promoting the development of beneficial gram-negative bacteria, such as *Megasphaera elsdenii* and *Selenomonas ruminantium* (Baungratz *et al.,* 2024). Marques and Cooke (2021) state that ionophores improve feed efficiency and weight gain in ruminants through the modulation of ruminal fermentation, increasing propionate production while reducing acetate and methane. This increase in propionate promotes gluconeogenesis and acts as a drain of H^+, maintaining an adequate ruminal pH and reducing energy losses.

The selective mechanism of ionophores is related to the structure of the bacterial membrane. While gram-positive bacteria are highly sensitive to these compounds, gram-negative bacteria exhibit resistance due to the presence of an outer membrane with porins, protein channels that limit the passage of molecules larger than 600 daltons (Da). Since most ionophores have a molecular mass above this limit, their penetration into gram-negative cells is prevented (Baungratz *et al.,* 2024).

With the aim of evaluating the effect of the combination of an antibiotic ionophore (monensin) with plant extracts and probiotics on carcass yield during the final fattening phase of lambs, Estrada-Ângulo *et al.* (2023) found that the combination of probiotics with monensin can improve the efficiency of dietary energy utilization in the finishing phase, and that the combination of plant extracts with the monensin + probiotics combination reduces carcass weight and yield, indicating the need for further research related to the effect of combining various sources of natural additives with synthetic antibiotics.

Buffering additives

The adoption of buffers in the diet of ruminants is conditioned both by the rearing system and by the type of feed provided. In animals kept exclusively on pasture, the use of these additives is usually unnecessary, as forages, rich in fiber, stimulate the secretion of large volumes of saliva, naturally abundant in buffering substances. In situations where the diet contains a high proportion of grains or is based on corn silage, supplementation with buffers aims to reduce the incidence of ruminal acidosis and, at the same time, improve fiber digestibility. These disorders result from the excessive production of organic acids in the rumen during microbial fermentation (Baungratz *et al*., 2024).

To be effective, ruminal buffers must have high solubility in water and an equivalence point (pKa) close to the physiological pH of the rumen (6,2–6,8) (Possamai *et al*., 2011). The inclusion of these compounds alters ruminal fermentation mainly by stabilizing pH and increasing the dilution rate of ruminal contents; the latter effect results from the increase in osmolarity, which induces greater water intake and fluid influx through the ruminal wall (Nagaraja *et al.,* 1987).

Several products with buffering properties are widely used in the feeding of ruminants, among which sodium bicarbonate stands out ($NaHCO_3$), magnesium oxide (MgO) and calcium carbonate

($CaCO_3$). The choice of the compound, as well as its dosage, depends on factors such as the composition of the diet, the production system, the animal species, and the specific characteristics of the product, including its concentration, form of presentation, and brand. Thus, the inclusion recommendations should follow specific technical and nutritional guidelines, considering the zootechnical objectives and the potential risks of mineral or metabolic imbalances (Baungratz *et al.*, 2024).

He *et al.* (2019) analyzed the effects of a grain-rich diet with a buffering agent on the hepatic metabolism of lactating goats and found that the grain-rich diet with a buffering agent alters the expression of proteins related to amino acid metabolism and glucose metabolism. Furthermore, feeding a grain-rich diet with a buffering agent may strengthen antioxidant capacity, stress capacity, slow down urea metabolism, and alter amino acid metabolism and glucose metabolism in the liver.

In a comparative study of ruminal buffering agents (AcidBuf, sodium bicarbonate, calcium powder, and WMC seaweed (Utva Lactuca extract)) on productive performance, ruminal fermentation, and meat quality of growing lambs, Alhidary *et al.* (2019) found that the addition of acidbuf, sodium bicarbonate, and seaweed to the diets improved feed efficiency, carcass quality with reduced body fat, and rumen characteristics of the lambs. El-nile *et al.* (2023) investigating dietary supplementation with nano and natural zeolite for goats, an improvement was observed in ruminal pH, nitrogen utilization, and total protozoa count. The authors report that nano zeolite is more effective in energy utilization, increasing the total concentration of short-chain fatty acids in the rumen and the proportions of butyric acid. In addition, nano zeolite increased serum calcium concentration and reduced total lipid and cholesterol concentrations. Both types of zeolite reduced somatic cell count, while nano zeolite was more pronounced in increasing the fatty acid profile of goat milk compared to its natural form.

Propolis

Propolis is a resinous substance with a complex composition, produced by bees from different plant species. Its biological properties are directly related to its chemical composition, which varies according to the region of production and the time of collection. This variation represents a challenge for its use in phytotherapy, since differences in the local flora and collection conditions affect its physical, chemical, and biological properties (Felício *et al.*, 2025).

It presents in its composition a diversity of bioactive compounds, including sugars, alcohols, aliphatic and aromatic acids and esters, aldehydes, amino acids, fatty acids, ketones, steroids, flavonoids, proteins, vitamins, and minerals (Baungratz *et al.*, 2024). Among its main constituents, flavonoids, isoflavonoids, and phenolic acids stand out, responsible for its anti-inflammatory and antioxidant properties (Cavendish *et al.*, 2015). Regarding its antimicrobial activity, propolis demonstrates bacteriostatic action, mainly inhibiting gram-positive bacteria and, to a lesser extent, some gram-negative bacteria (Baungratz *et al.*, 2024). This property suggests that its addition to animal feed can inhibit the growth of proteolytic bacteria, reducing gas production and improving feed efficiency through better nutrient utilization.

Kabiloglu *et al.* (2025) investigating the effects of ethanolic propolis extract (EEP – 0, 3, and 6 mL/day) on performance and immune responses in weaned lambs, they observed that supplementation with EEP increased weight gain and improved feed conversion rate. The authors conclude that daily administration of 6 mL of EEP (equivalent to 1800 mg of propolis) in weaned lambs provides potential benefits in terms of weight gain, feed efficiency, cough response, and immunoglobulins (IgA and IgM). Stradiotti Jr. *et al.* (2004) studied the action of propolis extract on the *in vitro* fermentation of different foods and observed that propolis was effective in inhibiting gas production by ruminal microorganisms, as well as increasing the specific digestion rate of carbohydrates.

Khudadad *et al.* (2025) measured the effect of the aqueous propolis extract (0, 5, 10, and 15 mL of aqueous propolis extract per animal) over 12 weeks on the body dimensions and weight of weaned kids during the stressful life transition period. The authors concluded that administering aqueous propolis extract in appropriate doses can mitigate the effects of weaning stress, promote gastrointestinal health, and optimize growth performance. However, they recommend additional studies to observe the long-term responses, identify the ideal dosage, and evaluate the applicability of using aqueous propolis extract in different breeds and physiological stages to maximize its benefits in livestock management. Aşici *et al.* (2024) when investigating the effect of propolis applied to kids during the weaning period on heat shock protein genes, they reported that with the administration of propolis (0.4 cc) during the weaning period, there was a reduction in the expression levels of HSP27 by 1.08 times, HSP60 by 1.56 times, and HSP70 by 2.12 times at the end of 2 weeks, with treatment with propolis being recommended during weaning stress.

CONCLUSION

The use of additives in ruminant feeding represents a promising strategy to optimize productive performance, promote ruminal health, and make production systems more sustainable. However, their effectiveness depends on multiple factors, such as the type of diet, the physiological stage, and the animal category, as well as management conditions. Thus, the choice and proper use of additives should be based on scientific evidence and adjusted to the particularities of each system, always aiming for a balance between productivity, animal welfare, and environmental responsibility.

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