Chapter 07

Sustainable Strategies: Integration of Essential Oils in Ruminant Nutrition

Jesús Hernández-Ruiz[1], Ana Isabel Mireles-Arriaga[1]*, Liliana Aguilar-Marcelino[2], José Antonio Hernández-Marín[3] and Ilse Alejandra Huerta-Arredondo[1]

[1]División de Ciencias de la Vida, Departamento de Agronomía, Universidad de Guanajuato, México*
[2]Centro Nacional de Investigación Disciplinaria en Salud Animal e Inocuidad, INIFAP, México
[3]División de Ciencias de la Vida, Departamento de Medicina Veterinaria y Zootecnia, Universidad de Guanajuato, México
*Corresponding author: ana.mireles@ugto.mx

ABSTRACT

Essential oils (EOs) have shown capacity to adjust rumen ferment action and heighten nutrient usage, impacting critter vigor and doingness. Albeit hopeful, their utilization confronts obstacles such as likely antifeed nutrient effects and alterations in the flavor of beast yields, which might impinge on dry matter consumption. Plus, inconsistency in measurement and the chemical makeup of the EOs utilized, alongside variances in feedstuffs and beastly physiognomy, present difficulties. The future is seen in nutrigenomics to direct cud-chewer foodstuff crafting, aiming at evaluating existent hurdles and suggesting fresh pathways for the domain. Henceforth, this passage gifts a broad view of EOs blended into cud-chewer sustenance through these points: impacts on ruminal fermentation plus microbial ecosystem; antimicrobe potency, influence on ruminant outputting, antibiotic substitutes; also, methane management.

KEYWORDS		
Antimicrobial activity, Methanogenesis perspectives, Ruminal fermentation, Ruminant nutrition essential oils	Received: 13-May-2024 Revised: 19-July-2024 Accepted: 16-Aug-2024	A Publication of Unique Scientific Publishers

Cite this Article as: Hernández-Ruiz J, Mireles-Arriaga AI, Aguilar-Marcelino L, Hernández-Marín JA and Huerta-Arredondo IA, 2024. Sustainable strategies: integration of essential oils in ruminant nutrition. In: Zafar MA, Abbas RZ, Imran M, Tahir S and Qamar W (eds), Complementary and Alternative Medicine: Essential oils. Unique Scientific Publishers, Faisalabad, Pakistan, pp: 63-70. https://doi.org/10.47278/book.CAM/2024.173

INTRODUCTION

Chemical Composition of Essential Oils

In a vast spectrum of vegetation, essential essences (EOs) are located, with notably essential vegetal families including Lamiaceae, Lauraceae, Asteraceae, Myrtaceae, and Rutaceae standing out. To derive essential essences from various plant parts such as bark, seeds, roots, stems, flowers, and leaves, steam distillation, solvent extraction, cold pressing, and expression techniques are commonly used. The chemical blend of EOs is recognized for being complex, consisting of small molecules such as long-chain hydrocarbons, acids, alcohols, aldehydes, phenols, non-ring esters, and lactones, which may vary within the same plant species (Kim et al., 2022). However, certain species possess signature compounds, such as Cinnamomum verum, where Cinnamyl acetate is listed in Table 1.

Several studies have focused on evaluating the chemical composition of essential oils, as it plays a crucial role in their potential use in ruminant nutrition and production. According to Wells (2023), 28 species of essential oils have been used in ruminant feeding, grouped into 15 botanical families, with the most representative being the Lamiaceae family, which includes six species: Oregano (*Origanum vulgare*), Mexican oregano (*Lippia berlandieri*), Poliomintha longiflora, Thyme (Thymus vulgaris), Peppermint (*Mentha* x *piperita*), and Lavender (*Lavandula angustifolia*) (Table 1).

Oil extracts are paramount from three species: *Lippia berlandieri*, *Poliomintha*, or *Origanum vulgare*, which are critical sources of terpenoids such as carvacrol, thymol, p-cymene, γ-terpinene, limonene, caryophyllene, myrcene, and humulene (Noriega et al., 2022). Garlic essential oil (*Allium sativum*) contains disulfide components including sulfur-like disulfide, trisulfide, and diallyl tetrasulfide dimethyl, along with trisulfide (Saharan et al., 2023). These compounds present in essential oils impart antibacterial qualities directly related to methane reduction when introduced into the diets of ruminant creatures as part of their routine food intake (Kholif et al., 2017).

Within the genus of plants known as Cymbopogon, an extraction process for essential oils takes place among three varieties: *C. citratus*, *C. nardus*, and *C. martini*. The substances extracted include aldehydes (such as Citral and Citronellal), alcohols (such as Geraniol and Linalool), esters (with Geranyl acetate present), as well as Limonene, β-Caryophyllene, and Elemol. These compounds have a specific ability to affect rumen activities while also acting as antioxidants and addressing hyperammonemia conditions (Kholif et al., 2017).

Table 1: Major plant species, compounds, method of application, and biological activity of essential oils (EOs) used in Ruminants (Source: adapted and modified from Wells, 2023).

Plant Species	Main Compounds:	Mode of Use	Biological Activity:	Ruminant Type
Allium stavium	Diallyl disulfide Diallyl trisulfide Sulfur compounds	feed additive	antimicrobial, anti- parasitic	Bovine, sheep
Artemisia afra	α-thujone 1,8-cineole β-thujone Camphor	oral drench	anti-parasitic	Bovine
Azadirachta indica	Azadirachtin Nimbin Salannin Nimbidin	external	acaricidal	Bovine
Capsicum spp	Capsaicin Dihydrocapsaicin Nordihydrocapsaicin Homocapsaicin	food additive, external, fumigation	milk production, ruminal function, heat stress, methane reduction	Bovine, sheep
Cedrus atlantica	α- Himachalene γ- Himachalene δ-Cadinene α-Cadinol	external	anti-parasitic	Bovine
Cinnamomum verum	Eugenol Cinnamyl acetate α- Transcinnamaldehyde β- Caryophyllene	feed additive	mastitis	Bovine
Citrus spp.	Limonene Citral Linalool Octanal	feed additive, external	antimicrobial, rumen function, mastitis	Bovine
Coriandrum sativum	Linalool Camphor α-Terpineol g-Terpinene	feed additive	rumen function, methane reduction, heat stress	Bovine
Cymbopogon citratus	Citral Geraniol Limonene Citronelal	external	anti-parasitic	Bovine
Cymbopogon martini	Geraniol Geranyl acetate Linalool β-Caryophyllene	external	anti-parasitic	Bovine
Cymbopogon nardus	Citronellol Geraniol Elemol Citronellol	food additive	ruminal function, methane reduction, heat stress	Bovine, sheep
Foeniculum vulgare (hinojo)	Linalool Estragole Fenchone Limonene	intranasal (BRD), food additive	Antimicrobial.	Bovine
Juniperus communis	α-Pinene β-Myrcene δ-3-Carene Terpinolene	food additive	milk production	Bovine
Lavandula angustifolia	Linalool Linalyl acetate 1,8-cineole Borneol	external mammary, infusion	Antimicrobial, acaricidal.	Bovine
Melaleuca alternifolia	Terpinen-4-ol γ-Terpinene α-Terpineol 1,8-cineol	external	acaricida	Bovine

Mentha x piperita	Menhtol Menthone Menthyl acetate Limonene	food additive	milk production, heat stress, antiparasitic. External: antiparasitic	Bovine, sheep
Origanum vulgare, Lippia berlandieri, Poliomintha longiflora	Carvacrol Timol 1,8-Cineol Estragole Borneol	feed additive, externa	antimicrobial, milk production, rumen function, methane reduction, heat stress	Bovine
Pelargonium graveolens	Citronellol Geraniol 10-epi-γ-eudesmol Guaiol	external	antiparasitic	Bovine
Pimpimella anisum	Anethole Estragole Methylchavicol Foeniculin	food additive:	antimicrobial, milk production	Bovine
Salvia rosmarinus	1,8-cineol α-pinene β-pinene Camphor	food additive	antimicrobial, ruminal function	Bovine
Senecio barbertonicus	Santolinatriol Sentequinone Senecionanetin Senecionine	oral drench	antiparasitic.	Ovinos
Sonchus congestus	Germacrene D β- Caryophyllene δ-cadinene Camazulene	oral drench	antiparasitic.	Sheep
Syzygium aromaticum	Eugenol β- Caryophyllene Eugenyl acetate α-Humulene	food additive, external, fumigation	antimicrobial, milk production, ruminal function, methane reduction, heat stress.	Bovine
Thymus vulgaris	Thymol Carvacrol p-Cimene γ-Terpinene	external mammary infusion, external, intranasal (BRD), external (mastitis)	antimicrobial, ruminal function, methane reduction.	Bovine
Zingiber officinale	Zingiberene Ar-curcumene 1,8-cineole β-bisabolene	external	antiparasitic, bactericidal	Bovine

Let's journey into the realm of cinnamon essential oil, where we're discussing the species known all fancily as *Cinnamomum verum*. It's rich with Aldehydes, featuring α-Transcinnamaldehyde, the classic spicy-smelling Cinnamaldehyde, and its cousin, (E)-Cinnamaldehyde. Let's not overlook those Esters making their mark, with "Cinnamylish" acetate taking the stage in its alternate universe version, ((E)-Cinnamamide acetate). There's also a gathering of Terpenoids here, with β-Caryophyllene joining Pinene, Phellandrene, Limonene, Copaene, and Caryophyllene oxide. All wrapped up under the observation of Farag et al. (2022), this cinnamon ensemble is gearing up nicely against threats like Aspergillus and Candida albicans. They've positioned themselves as contenders, potentially outshining conventional disinfectants in the ongoing battle within livestock production systems.

Nevertheless, it is important to recognize that the density of substances within the EO can fluctuate based on elements like Geographic location, developmental phase of the plant, type of plant, method used for extraction, and also the amount and technique used in its application (Schären et al., 2017).

Effects on Ruminal Fermentation and Microbial Ecology

Oils of essence underwent examination for impacts on population’s microbial rumen and procedures fermentative. It was demonstrated that essential oils, due to its active compounds, impact the fermentation of ruminal microbial and nutrient flow (Paraskevakis, 2018). These components can sway the creation of by-products fermentation like acetate, butyrate, formate, lactate, hydrogen, and ammonia by bacteria gram-positive in the rumen showing that oils essences possibly change fermentation in rumen by bettering efficiency use energy plus lessening emissions methane (Zhou et al., 2020). Yet, several writers signal that outcomes are erratic concerning the influence of essential essences on stomach fermentation and beast efficiency. This could stem from inconsistency in portioning and chemical makeup of the vital essences applied, as well as fluctuations in feedings and creature science (Schären et al., 2017).

A concoction of critical extracts from clove, marjoram, cinnamon bark, and citron shows potent anti-life action towards rumen single-celled life forms and gram-positive microbes, impacting the generation of assorted fermentative side-products such unmixed propionic acid derivative esterified additive $C_2H_3O_2^-$ anion radioactive carbon series liquid antecedent nitriles ammonia mixed (Lin et al., 2013).

Oil extracts mixtures trim down the occurrence of ancient one-celled organisms protozoa's specific small living entities within stomachs altering ruminant microbial assembly. Adding strong scents to lamb sustenance influences tummy agitation by lessening grub cell partition digestion (Barreto-Cruz et al., 2023).

Several studies have explored the effects of essential oils on digestion, ruminal fermentation, microbial populations, as well as milk production and composition in dairy cows. These studies emphasize the adaptation of rumen microbes to essential oils over time and discuss potential limitations in improving nutrient utilization and milk production in dairy cows (Benchaar, 2021).

Antimicrobial Activity

Significant attention has been attracted by essential oils within the domain of ruminant nutrition for their antimicrobial traits and potential influence on ruminal microbial fermentation, nutrient usage, and efficiency in milk production. Active elements are contained in essential oils which show antimicrobial functions across a broad spectrum of microorganisms that includes bacteria (gram-negative and gram-positive), protozoa and fungi (Benchaar et al., 2008). These antimicrobial effects have been attributed to various small terpenoid and phenolic compounds present in essential oils. Additionally, essential oils have been suggested as alternatives to traditional antimicrobials such as monensin, aiming to enhance feed efficiency, nutrient utilization, and milk yield in ruminants (Benchaar, 2020).

Investigations unveil that EO mixtures might sway the microbial brewing in the rumen by tweaking elements like the complete sum of volatile chunky acids (VFAs) and propionate turnout. Besides, discoveries denote that crucial oils along with their terpenic parts sway the metabolism within the rumen, microbial tribes, and eventually bear upon parameters linked with milk yielding (Lejonklev et al., 2016). Such influences on ruminal fermenting and microbe groupings underscore the promising use of essential essences as fodder enhancements for cud-chewing beasts. Moreover, exploring has been done on how vital scents adjust bacterial colonies engaged in fatty acid biohydrogenation inside the rumen which might provoke shifts in fatty acid profiles within dairy and flesh outputs from cud-munchers (Liu et al., 2020). While critical aromatic compounds exhibit promises in exerting anti-microbic actions and amping up certain slices of ruminal operation, divergent outcomes have been logged concerning their impact on fermentation inside ruminants' stomachs, consumption rate of nutrients, plus dairy generation among milking bovines (Benchaar, 2021). These disparities could be pinned to variables such as distinct essential scent blends utilized doses put into feed-specific nourishment practices for animals altogether clubbed with trial surroundings.

Impact on Ruminant Production

In general, the addition of EOs to the diets of small ruminants (goats and sheep) improves the Average Daily Gain (Andri et al., 2020). It has also been suggested that essential oils could potentially influence ruminal fatty acid biohydrogenation, thereby affecting the quality of milk and meat produced (Zhou et al., 2020). This effect is partly related to the antimicrobial activity of essential oils, which reduces the population of ruminal protozoa, potentially increasing microbial protein and energy supply, ultimately enhancing the growth rate of small ruminants (Soltan et al., 2018).

The addition of a supplement of EOs from anise, cinnamon, garlic, rosemary, and thyme in pre-weaned calves improves immunity and lower fecal scores in the pre-weaning phase. Hence, essential oils are a healthy additive option for modern production systems and could be used as an alternative to enhance calf health and performance (Palhares et al., 2021).

The essential oil of Greek oregano (*Origanum vulgare*), provided at doses starting from 1 mL in lactating Alpine goats, increases the activity of the enzymes glutathione peroxidase and reductase in both blood and milk, enhancing the antioxidant system and helping to minimize oxidative damage during lactation (Paraskevakis, 2018). In dairy cows, supplementation with oregano EO may alter the organoleptic characteristics of milk, without showing effects on feed conversion (Lejonklev et al., 2016; Hadrová et al., 2021). Supplementation with garlic extract (*Allium sativum*) in goats and sheep can increase milk production, protein content, and non-fat solids. However, it decreases the percentage of fat and non-protein nitrogen in milk (Ding et al., 2023).

The inclusion of rosemary essential oil (*Salvia rosmarinus*) in goats' diet improved nutrient digestibility, ruminal fermentation without affecting pH, daily milk production, fat and protein content, and at a dose of 230 g/animal/day in goats reduced milk coagulation time, decreased C10:0 and C14:0 fatty acids content, and increased the percentage of C17:0, C18:2 fatty acids, and polyunsaturated fatty acids (Smeti et al., 2021). This effect is similar to that reported by Kholif et al. (2017) when using lemongrass (*Cymbopogon citratus*) as a supplement in goats' diet.

In dairy cows, the addition of rosemary extract to their diet increases production and content of fats, proteins, and lactose, while reducing the number of somatic cells (white blood cells and epithelial cells) present in milk (Kong et al., 2022).

Moringa oleifera leaf extract at doses of 10 to 40 mL daily improves milk production by up to 6% in Nubian goats and increases total solids, non-fat solids, fats, proteins, and lactose in milk (Kholif et al., 2019).

The incorporation of rosmarinic acid, a chemical compound present in various plants, especially in the Lamiaceae family, in combination with probiotics as a food additive can increase average daily gain, starter intake, and total dry matter intake (Stefańska et al., 2021).

Alternative to Antibiotics

In intensive animal production for feed, antibiotics are used to prevent and treat various bacterial diseases. However, they are also used as a food additive to enhance the effectiveness of ingested foods in products for human consumption, such as milk and meat. This excessive and inappropriate use of antibiotics has led to the emergence of bacterial resistance, posing a threat to global health (Benchaar et al., 2020; Haulisah et al., 2021).

The most used antibiotics are a) tetracyclines, such as oxytetracycline, which are commonly used due to their broad-spectrum activity against a wide range of Gram-positive and Gram-negative bacteria (Almaraz-Buendía et al., 2019); b) penicillin, such as amoxicillin, frequently used in the treatment of respiratory and skin infections in ruminants; c) macrolides, particularly azithromycin, are commonly prescribed due to their anti-inflammatory and immunomodulatory properties, which are beneficial in managing respiratory diseases in ruminants (Montoya et al., 2022).

EOs are proposed as a sustainable alternative to antibiotics in the livestock sector, due to their antimicrobial properties and safety. For example, thyme and oregano oils exhibit strong antimicrobial and antioxidant activities. It is important to note that the antimicrobial activity of EOs is influenced by their chemical composition, and certain components such as carvacrol, thymol, and eugenol which play a significant role in determining their effectiveness against microorganisms (Redondo et al., 2021).

Below, studies on the use of essential oils that have proven to be effective in controlling bacteria and nematodes are discussed, suggesting their potential for disease control in ruminant livestock.

EOs from *Rosmarinus officinalis* (rosemary), *Melaleuca alternifolia* (tea tree), and *Cinnamomum cassia* (cassia) have high antimicrobial activity (Abers et al., 2021).

Extracts from *Caesalpinia spinosa* showed antimicrobial effect on antibiotic-resistant strains of *Staphylococcus aureus*. This study is relevant as it demonstrates the potential of extracts as an alternative to antibiotics and their potential application in animal health (Coral et al., 2022).

The essential oil of *A. sativum* has been shown to be effective in controlling nematode parasites in sheep, presenting the same effect as the synthetic agent albendazole at 10% (Masamha et al., 2010).

There are other EOs that have only been evaluated in vitro, such as the plants *M. afra* and *M. longifolia*, which are candidates for the treatment of gastrointestinal larval infections (Wells, 2023). Similarly, extracts from *Tithonia tubaeformis* have antioxidant and antibacterial effects on *Escherichia coli*, *Salmonella typhimurium*, *Salmonella enteritidis*, and Listeria (García-Vázquez et al., 2023). However, in both cases, the mechanisms of their in vivo efficacy have not yet been evaluated, and it is considered necessary to conduct in vivo safety and toxicity studies to determine the minimum non-lethal concentrations required for the treatment of infections in ruminants.

Methanogenesis Control

Methanogenesis is a biological process by which methane (CH_4) is produced by microorganisms called methanogens. This process is crucial in the degradation of organic matter in anaerobic environments, such as the rumen of ruminant animals and aquatic sediments. Methanogens are microorganisms belonging to the Archaea domain and are capable of synthesizing methane from organic substrates, such as hydrogen and carbon dioxide, or simple organic compounds, such as acetic acid.

Oregano oil and carvacrol are two essential oils that have been extensively studied for their ability to inhibit ruminal methanogenesis both in vitro and in vivo. These essential oils contain active compounds that can modulate ruminal microbial fermentation, potentially reducing methane emissions by affecting fermentation pathways and promoting alternative hydrogen sinks such as propionate production (Benchaar, 2020).

As evidenced by reports, aromatherapy fluids could enhance ruminant digestion by boosting volatile fatty acid production and decreasing methane emission by inhibiting the operations of bacteria responsible to produce methane. Ingredients like tannin compounds, soap-like materials, and ion transporters are likely causes of reducing methane levels in cud-chewing livestock through inhibiting methane-producing processes or dissolving digestion pathways. These agents can radically improve microbial populations within the stomach cavity, reducing emissions of gas and increasing feed utilization (Becker et al., 2023).

Challenges and Future Perspectives

Since EOs are hydrophobic and lipophilic, they could influence the ruminal environment in a similar way to antibiotic admixtures. The effects of EOs on bacterial membranes have been established in many studies and reduce microbial populations, contributing to a potential increase in the response. Other limitations include EOs' antinutritional qualities, modification of the product's palatability following animal acceptance, which might decrease dry matter intake (Almeida et al., 2021). Future perspectives lie in nutrigenomics, where ruminant nutrition engineering can be guided by assessing current challenges and proposing new directions for the field (Kizilaslan et al., 2022).

EOs, as volatile secondary metabolites of plants, are gaining popularity as alternatives to traditional growth-promoting antibiotics, offering a sustainable approach to improving ruminant nutrition (Nel et al., 2021). They have the potential to reduce ruminal protozoa populations, increase microbial protein and energy supply, and ultimately improve growth rates in small ruminants (Andri et al., 2020). The use of EO may contribute to methane mitigation in ruminant production systems, aligning with sustainable practices (Durmic et al., 2021). By harnessing plant bioactivity to reduce methane, strategies involving low-methanogenic forage species and plant-derived by-products can offer renewable solutions with minimal impacts on forage digestibility, especially if complemented with EO positively impacting ruminal fermentation and microbial communities, to enhance the health attributes of animal products (Zhou et al., 2020).

Conclusion

One potential perspective is nutrigenomics, as the application of essential oils in the nutrition of ruminants is a substitute for chemosynthesis drugs, increases the animal's well-being and productivity. The overall daily increase in weight with a EO does not harm feed intake and FCR. Their use influences animal products as the acids in milk can contribute to meat preservation, reducing the need for additives. One significant effect of EO use is the reduction of enteric methane production. However, there are still controversial outcomes as ruminal microbiota can adapt to EO presence, diminishing antimicrobial and antiparasitic effects or reducing food degradation by minimizing volatile fatty acid production, thus making certain essential nutrients less accessible for animal development.

The generation of new *in vivo* research is essential, considering parameters such as dosage, addition method to the diet, duration of use, age and species of the animal, as well as the synergistic effect with other compounds like phenolics or animal diet ingredients.

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