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Potential effects of essential oils in safeguarding the health and enhancing production performance of livestock animals: The current scientific understanding

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ABSTRACT

The food sector competes in a cutthroat environment, and it constantly struggles to maintain or even grow its market share. For customer confidence and consumption to remain strong, consistent animal products are needed. The qualitative attributes of the derived goods appear to be improved by the addition of bioactive substances to food, such as essential oils (EOs), and consumers are shielded from the impacts of bacterial and oxidative deterioration. Due to the current controversy surrounding synthetic chemicals and their alleged carcinogenic potential, a substantial study has been done to find effective and safe substitutes. Aromatic plants and the corresponding EOs from them are considered natural products and are typically employed in ruminant nutrition. Since dietary supplementation has been demonstrated to be an easy and practical method to successfully suppress oxidative processes or microbial deterioration at their localized sites, the addition of EOs in animal diets is now becoming a

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regular practice. However, there is just a little amount of evidence supporting the notion that these compounds may improve nutrient absorption and gastrointestinal health. Additionally, a variety of factors affect how well EOs works in animal diets. These variables can be, on the one hand, the erratic composition, and the many additions to the diet, and, on the other hand, erratic animal genetic elements. Maximizing the use of EOs and creating high-quality products require a deeper understanding of the composition and activity of the gastrointestinal tract microbiota. Numerous EOs contain bioactive substances with the potential to serve as multifunctional feed supplements for animals, with impacts on growth performance, the digestive system, the growth of pathogenic bacteria, and lipid oxidation, among others. To establish their regular use in animal production and to determine their precise mechanism of action, more research is required. The potential advantages of EOs for livestock health and production are highlighted in the current article.

1 Introduction

Essential oils (EOs), sometimes called volatile oils, are fragrant liquid distillates that come from various plant parts like flowers, buds, seeds, leaves, twigs, bark, wood, and roots (Miguel 2010). These extracts have been utilized traditionally for millennia in a variety of regions of the world, and are either steam-volatile or natural-solvent (ethanol, methanol, toluene, or other natural solvents) based. They are regarded as having high-quality flavor and scent in addition to having preservation properties (Prakash et al. 2021a; Prakash et al. 2021b). Certain EO additions can be derived naturally from plants, while others can be synthesized. Terpenes, alcohols, acetones, phenols, acids, aldehydes, and esters are just some of the many chemicals that are commonly found in EOs (Negi 2012). These substances may operate as a barrier against microbial, fungal, or insect invasions. Therefore, EOs can be categorized as herbal oils, complex oils with several factors, and oils with multiple uses (Brenes and Roura 2010; Abd El-Hack et al. 2016; Andri et al. 2020; Buttar et al. 2022). Plant-based feed additives including herbs and their metabolites, phytochemicals, aromatic plant extracts, and their constituent's essential oils have found promising beneficial applications for use as feed additives, and also possess benefits against the usage of conventional antibiotics in livestock animals and poultry (Dhama et al. 2014; Alagawany et al. 2015; Yadav et al. 2016; Dhama et al. 2018; Tiwari et al. 2018; Kuralkar and Kuralkar 2021; Nehme et al. 2021; Uddin et al. 2021; Chandran 2021a; Zhang et al. 2022).

EOs were utilized for their flavoring capabilities and for their capacity to be used as food preservatives since they lengthen the shelf lives of products or reduce the concentration of Clostridium spp. Over the past decade, the use of EOs in the animal field and medicine has skyrocketed. Their potential as antioxidants and immunomodulators in the ruminant region, however, is still insufficiently investigated (Burt 2004; Corbo et al. 2009). Studies have shown that some EOs can increase animal performance and productivity, particularly in the chicken and pig industries, by enhancing digestive secretions (Lambert et al. 2001); increasing the diversity of probiotic bacteria, including *Lactobacillus* spp. (Gill and Holle 2006; Raybaudi-Massilia et al. 2009); stimulating the immune feature and the gastrointestinal microbiota (Oussalah et al. 2006). However, there are still significant discrepancies about the efficacy of EOs, particularly associated with the nature of the compounds and some intrinsic and extrinsic factors such as infection, dietary reputation, environment, and, most importantly, diet composition (Ultee et al. 2002; Saleena et al. 2021a; Saleena et al. 2021b). It is important to note that the genetics, geographical origins, agricultural practices, and harvesting seasons of individual plant species all influence the unique chemical makeup of their respective EOs (Juliano et al. 2000). EOs mostly consists of terpenoid and phenylpropanoid derivatives. About 80% of the EOs from most plants are terpenoids, however, phenylpropanoid derivatives add significant flavor, piquancy, and odor to the EOs (Faleiro et al. 2003).

EOs have a useful role in the fermentation process in the rumen. EOs, due to their antibacterial qualities, can regulate rumen metabolism. Methane, a type of hydrocarbon, is the fuel source from which natural gas is created. EOs from plants including garlic, clove, eucalyptus, origanum, and others are effective in lowering methane emissions (Deepak et al. 2020a; Kumari et al. 2022). *In vitro* batch culture shows that EOs and their constituents can improve nitrogen and potential utilization in ruminants. It is believed that the effects of EOs on ruminal nitrogen metabolism are mediated by their effect on hyper-ammonia producing bacteria, leading to a decrease in amino acid oxidation and ammonia nitrogen synthesis. The natural antioxidants in EOs benefit animal health by reducing oxidative stress, and they also help the food industry by halting the oxidative processes that lead to spoilage. Natural antioxidant uses of EOs are an exciting new area of research. This is because the safety of some synthetic antioxidants, such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT), has been called into question, especially when it comes to animal consumption. EOs have beneficial effects on antioxidative enzyme activity and inhibit the generation of reactive oxygen species, two factors in lipid metabolism in animal tissues. High antibacterial action was indicated, and EOs are effective against both gram-positive and gram-negative bacteria (Panghal et al. 2011). The concentration of EOs is directly related to their antibacterial efficacy (Ultee et al. 2000). The effects of both room temperature and storage heat are detrimental. Among the several secondary metabolites found in many EOs, phenolic compounds have the greatest antibacterial activity. EOs are commonly used as preservatives in some foods. At concentrations of 5-20 µl/g, plant compounds like eugenol and coriander, clove, oregano, and thyme oils repressed *Listeria monocytogenes*, *Aeromonas hydrophila*, and autochonous spoilage organisms in meat products (Skandamis and Nychas 2001), while mustard, cilantro, mint, and sage oils were either ineffective or less effective (Tassou et al. 1995). Because of their perceived safety, EOs and their derivatives are widely used in the feed industry. *In vivo* results suggest that EOs are included in animal diets as a natural means of promoting growth. EOs added to animal feed enhance both meat and milk quality. EOs make the meat softer because they include oxidation proteases. Milk total bacterial and somatic count, yield, and feed efficiency were all found to be enhanced when early lactation Holstein dairy cows were fed modest doses of an EOs mix consisting of clove, juniper, and oregano in the same proportion (Al-Suwaiegh et al. 2020; Deepak et al. 2020b; Patange et al. 2022a: Patange et al. 2022b).

EOs have been shown to have several positive benefits on livestock health and productivity, and those are the focus of this review. It tells us everything we need to know about the role of EOs in animal nutrition, from their effect on rumen fermentation and the digestive system to their antioxidant and antibacterial properties and their ability to modulate the immune system.

2 Essential oils (EOs)

Paracelsus von Hohenheim, a Swiss medical reformer, is credited with coining the word "essential oil" somewhere in the 16th century. He is also credited with coining the name of a beneficial component in the Quinta essential medication. Even though spices have been employed as preservatives, perfumes, and flavors in food since antiquity, turpentine oil is the only EO recorded in Roman and Greek history. A few thousand years ago, civilizations in the East, including Persia, India, and Egypt, began using distillation as a means of EO extraction. Pharmacological effects were not documented in pharmacopeias until the 13th century, and only then did pharmacies begin producing them. Before the development of the London market in the 16th century, European countries had little use for EOs (Dhama et al. 2014; Dhama et al. 2018; Dosoky and Setzer 2018; Kumar et al. 2022a; Kumar et al. 2022b). In the eighteenth century, when Europeans first settled in Australia, records began to appear detailing the medical use of tea tree oil (Carson and Riley 1993; Aziz et al. 2018). EOs are named after the fragrant properties of the plants they were extracted from. Since "essential oil" is a poorly defined term that dates back to the medieval pharmacy, the term "volatile oil" is being proposed as a replacement (Hoffmann 2020).

EOs are potent because they contain more characteristics than dry herbs and perform an essential function as a natural protection for host plants. Eos are fascinating not only for their therapeutic effects, but also for their antimicrobial, antiviral, antifungal, and bacterial characteristics. They are not only aesthetically pleasing but also have excellent scent and flavor preservation qualities (Bakkali et al. 2008; Aziz et al. 2018). EOs are also known as ethereal or volatile oils and are aromatic lipophilic liquids that are obtained from plant parts like flowers, leaves, twigs, bark, seeds, buds, herbs, fruits, roots, and wood (Miguel 2010). EOs are mainly obtained through enfleurage, expression, extraction, or fermentation but for the commercial production of EOs, the most commonly used method is steam distillation. Some components of the EO can be obtained not only from the plant parts but also from synthetic manufacture. As we have seen above, we know about 3000 EOs of which 300 are used in the commercial markets for flavouring and fragrance. The increase in the interest of scientists in these compounds is not only due to their antibacterial properties but also due to insecticidal, antiviral, anti-toxigenic, antimycotic, and antiparasitic properties. These properties may be the functions of the compound in the plants. EOs are natural and complex oils not only that they can be considered also multi-component oils (Brenes and Roura 2010; Hoffmann 2020).

Nowadays, EOs are used for a wide range of purposes. ‘DMC Base Natural’ is a commercially available natural food preservative made from 50% EO (sage, citrus, and rosemary) and 50% glycerol. Protea 1 and Protea 2 by 'Bravia Corp.' are a standardized extracts of a proprietary blend of herbs (Cutter et al. 2000). Perfumes and aftershaves are only two examples of how EOs can be employed in the beauty industry. Pure molecules of EOs are employed in a variety of applications, including animal feed supplements, antiseptics, and oral care products. Due to their enhanced biological activities as antioxidant, antibacterial, and antifungal, EOs are of tremendous interest in the cosmetic, pharmaceutical, and food supplement industries (Leherbauer and Stappen 2020).

3 Chemical composition and bioactive in essential oils

The genetics, geographical origins, farming practices, and harvesting seasons of different plant species all affect the unique chemical makeup of their respective EOs. There will be a wide variety of similar-looking chemical compounds produced by these variants. The addition of fertilizers like phosphorus and potassium nitrogen will alter the EOs' chemical makeup and raise their yield. The enzymes that catalyze the biosynthesis of organic compounds like terpenoids will proliferate in response to fertilizers (Jerkovic et al. 2001). *Rosmarinus officinalis* EOs derived through irrigation show more variety than EOs obtained from non-irrigated plants such as linalyl-isobutyrate and trans-verbanol, indicating that irrigation will impact EO quality. EOs extracted from herbs at or around the end of blooming will be the most potent in terms of antibacterial action. Elements of EOs, such as enantiomers, have demonstrated impressive antibacterial efficacy (Marino et al. 1999). Major components of EOs are phenylpropanoid and terpenoid derivatives. Most plants' EOs include around 80% terpenoids, however, the presence of phenylpropanoid gives the EOs its notable flavor, piquant, and smell. These are the two principal metabolites that have been most successfully extracted (Brenes and Roura 2010; Hoffmann 2020; Leherbauer and Stappen 2020). The selected EOs' main features are listed in Table 1, and their major bioactive components are depicted in Figure 1.

EOs are predominantly found in plant tissues, specifically in their glands and intercellular spaces. The seeds and blooms of plants usually contain the highest concentrations of EOs. The majority of EO ingredients evaporate easily in water steam. Although "Esters" are often cited as the main culprits behind the aroma and fragrance of fruits and flowers, it is important to note that other components may also contribute to the taste and scent. The remaining parts are a complicated combination of EOs such as alcohols and carbonyl, as well as hydrocarbons. These chemicals are mostly found in two

Table 1 Significant essential oils and their major bioactive components

Plant name	Botanical name	Major bioactive component	Percentage composition	Major plant part
Thyme	*Thymus Vulgaris*	Cymene Thymol Terpinene	8.41 47.59 30.90	Leaves Flowers
Ginger	*Zingiber officinale Rosc*	Neral β-Eudesmol Ar-curcumene Camphene β-Bisabolene	4.9 5.4 14.5 14.1 22.1	Roots
Bergamot	*Citrus bergamia*	Limonene Linalyl acetate Linalool β-Pinene	59.21 16.83 0.51 4.38	Bark
Sandalwood	*Santalum album*	β-santalol α-santalol	18 43	Heartwood
Lavender	*Lavandula officinalis*	β-farnesene Linalyl acetate β-caryophyllene Lavandulol acetate Linalool	0.9 4.6 0.6 0.8 28	Leaves Flower spikes
Eucalyptus	*Eucalyptus citriodora*	Citronellol Citronellal	14.5 72.8	Leaves
Jasmine	*Jasminum grandiflorum*	Benzyl benzoate Benzyl acetate Linalool Eugenol Geranyl linalool	20.7 23.7 8.2 2.5 3.0	Flowers
Peppermint	*Menthae piperitae*	Limonene Menthol Menthyl acetate Menthone 1,8-Cineole	2.6 40.7 4.2 23.4 5.3	Fresh leaves
Cinnamon	*Cinnamomum zeylanicum*	Eugenol Cinnamaldehyde	7.2 77.1	Inner bark
Clove	*Syzygium aromaticum*	β-Caryophyllene Eugenol Caryophyllene oxide	11.54 76.23 4.29	Dried flower buds
Rosemary	*Rosemarinus officinalis*	1,8-Cineole β-pinene α-pinene Camphor	43.6 5.0 7.4 12.3	Whole plant

Source: Brenes et al. 2010; Aziz et al. 2018; Plant et al. 2019; Hoffmann 2020; Leherbauer and Stappen 2020

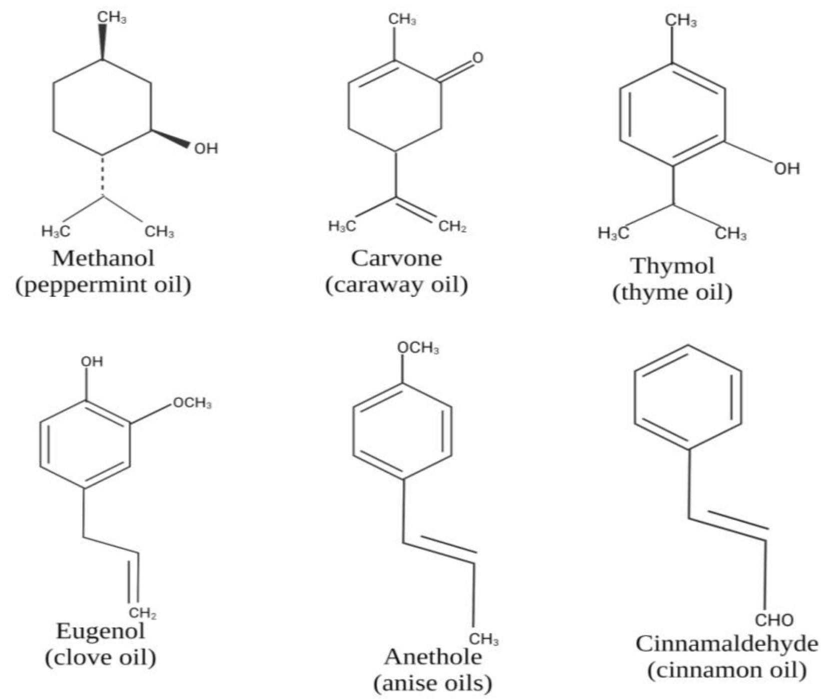

Figure 1 Major bioactive component of essential oils

classes of natural products: terpenes and phenylpropanoids (Plant et al. 2019). Some plants use the shikimic acid pathways to produce phenylpropanoids, or cinnamic acids, from tyrosine and phenylalanine. Phenylpropanoid molecules have a six-carbon based aromatic phenol group coupled primarily to 3-carbon propene tailoring cinnamic acid. Ethanol, myristicin, vanillin, safrole, and cinnamaldehyde are all phenylpropanoids. Both anethole and myristicin have been shown to have anticancer qualities, with the latter also exhibiting anti-inflammatory and anti-proliferative effects, while safrole encourages biological processes such as antibacterial and antifungal ones (Sharma et al. 2019; Eid and Hawash 2021).

Isopentenyl diphosphate is the progenitor of all terpenes, including primary and secondary metabolites numbering over 25000 substances. Named thus because the first few members were first extracted from turpentine, "terpene" refers to any of several related compounds. Due to the thermal decomposition of terpenoid compounds into the alkene gas isoprene, the monomer with five carbon atoms is most commonly referred to as isoprene. Hemiterpenoids, monoterpenoids, sesquiterpenoids, diterpenoids, sesterterpenes, triterpenes, and tetraterpenes are the seven basic categories into which terpenoids fall based on the number of isoprene units they contain. Both antibiotic-resistant and antibiotic-susceptible bacteria are susceptible to the antimicrobial effects of terpenes, which include the promotion of inhibition of protein and DNA synthesis and the prevention of cell rupture (Plant et al. 2019; Hoffmann 2020). Terpenoids, a class of secondary metabolites found in medicinal plants, play a crucial role in the plants' ability to ward off disease. This is because terpenoids, particularly monoterpenoids, have antibacterial properties, disrupt metabolic processes, and in some cases even have pest-repellent effects (Burt 2004; de Matos et al. 2019). Leucine, valine, polyketides, sulphur components, methionine, lipids, isoleucine, and alanine are some of the most common amino acid-derived components found in EOs such as allicin, cis-jasmone, jasmonic acid, and methyl jasmonate (Pandey et al. 2017).

4 Effect of essential oils on rumen fermentation

EOs have a useful purpose in the rumen fermentation process. It may have something to do with ruminants' ability to generate high-quality protein via synthesis. Methane and ammonia, both of which are produced during microbial fermentation, are both significant environmental pollutants and a by-product of the process (Aziz et al. 2018). EOs, due to their antibacterial qualities, regulate rumen metabolism. Methane is the most abundant component of natural gas and a type of hydrocarbon. It has a 21 times greater impact on the potential for global warming than carbon dioxide does, making it another greenhouse gas. Depending on diet and feed, ruminants can save 2% to 12% of their total digested energy by reducing the amount of methane produced in their digestive tracts (Boadi et al. 2004; Cobellis et al. 2016). Thus, the use of EOs to reduce methane emissions is beneficial for both animals and the environment (Benchaar and Greathead 2011). The "hyper-ammonia-producing bacteria" in the rumen are responsible for the degradation of amino acids to ammonia through the influence of protein metabolism and a decreased rumen ammonia range, resulting in the efficient management of dietary nitrogen (Mclnotosh et al. 2003; Calasmiglia et al. 2007). In one of the experiments commercial blend of essential oil decreased methane production in Holstein-Friesian cows and increased milk yield (Hart et al. 2019). As they improve VFA production and utilization they can improve the production performance of animals and the quality of products (Simitzis 2017; Hart et al. 2019). Besides decreasing methane production, essential oil supplementation has reduced gross energy consumption, apparent total tract digestibility, and rumen valerate concentration in beef heifers (Jiménez-Ocampo et al. 2022).

Many EOs, including garlic, clove, eucalyptus, origanum, etc., can help achieve the goal of decreased methane generation. The importance of EOs in ruminal fermentation has not been exaggerated, but at high concentrations, these substances are toxic to the beneficial bacteria in the rumen as well as the targeted microorganisms (Benchaar and Greathead 2011; Benetel et al. 2022). EOs can be tested in vitro to determine how they influence factors including food, time, and pH to reduce methane production, total volatile fatty acid concentration, and feed digestion. The *in vitro* effects of EOs on ruminal fermentation at high levels could be applied realistically in vivo, having an inhibiting influence on feed palatability, digestion, and animal output. Positive *in-vitro* responses will be achieved despite the rising cost and toxicity associated with EO production (Beauchemin et al. 2009; Poudel et al. 2019). There will be no change in consumption, average daily procures, or concentration of total volatile fatty acids and rates after the main observation of dietary complement of ruminants with EOs in the form of single compounds and mixes. As a result, the benefits of rumen methanogenesis do not convince. Rumen microorganisms' capacity to metabolize and modify volatile oils provides a plausible explanation (Benchaar et al. 2011; Aziz et al. 2018; Ku-Vera et al. 2020). Figure 2 provides the impact of EOs on microbial fermentation in the rumen.

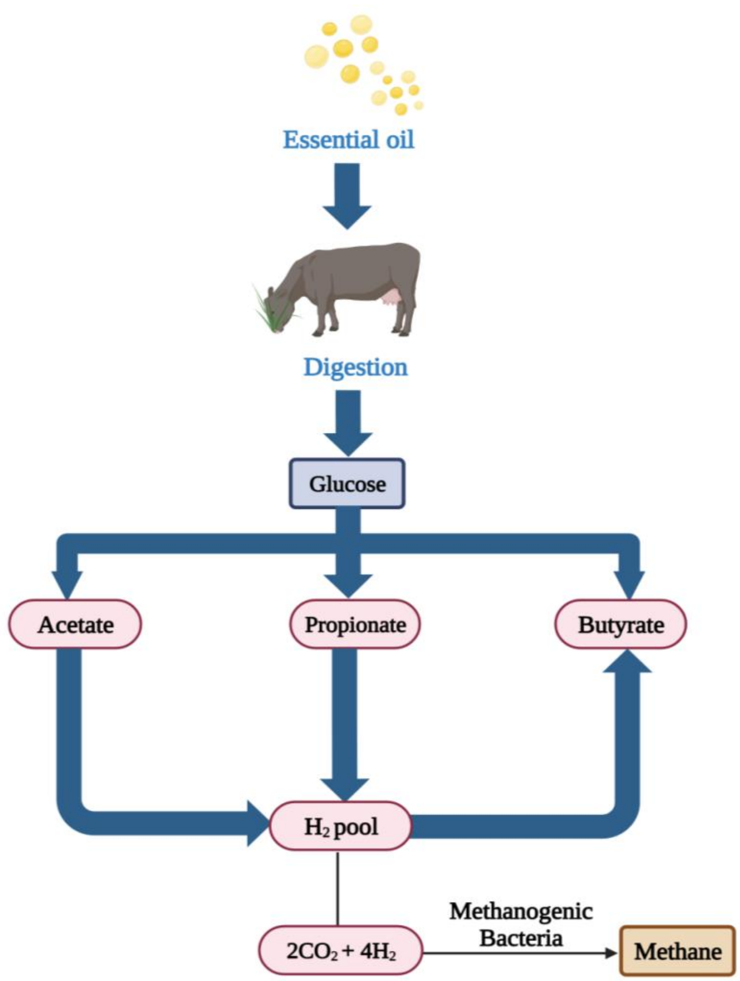

Figure 2 Impact of essential oils in the microbial fermentation pathway in the rumen

Table 2 Effects of essential oils or their components on rumen characteristics

Essential oil or component	Level of incorporation	Animal	Effects on rumen metabolism
Coriander oil	14 ml/day	Domesticated cow	Increased milk yield, nutrient, and digestibility
Mood essential oil	25 g/day	Domesticated cow	Improved carcass oil, cow quality, milk yield, and feed efficiency
Thyme	100 g/day	Domesticated cow	Increased milk yield
Cashew and caster	2 g/day	Domesticated cow	Alter the ruminal pH
Orgenao	100-150 mg/kg	Domesticated cow	Improved feed efficiency and reduced incidence of diarrhoea
Blend of essential oils	1 g/day	Domesticated ruminants	Increase Immunity; improvement and better feed efficiency
Thyme	1.25 g/kg	Domesticated sheep	Increased nutrient; metabolism and rumen fermentation

Source: Greathead 2003; Cobellis et al. 2016; Aziz et al. 2018; Poudel et al. 2019; Ku-Vera et al. 2020; Dorantes-Iturbide et al. 2022

4.1 Dietary ruminal effects of essential oils

In response to the emergence of antibiotic-resistant bacteria and the spread of these pathogens from livestock to humans, the efficacy of pharmacological materials in ruminants has improved. Alterations to rumen metabolism that increase feed productivity and animal health have been lauded in a variety of ways. Processing of microbial activity takes place in the rumen to build an energy source with antibacterial characteristics to substitute antibiotics (Benchaar et al. 2011; Ku-Vera et al. 2020). EOs and their constituents can improve nitrogen and potential ruminant utilization through in vitro batch culture. It is believed that the effects of EOs on ruminal nitrogen metabolism are mediated by their effect on hyper-ammonia producing bacteria, leading to a decrease in amino acid chemical alterations and ammonia nitrogen synthesis. There is conflicting evidence regarding the effects on methane generation, however, current data suggests that it is possible to select EOs or other hand-active components that selectively inhibit ruminal methanogenesis (Benchaar et al. 2008; Dorantes-Iturbide et al. 2022). There is currently no evidence that aromatic plant EOs have antibacterial activity in ruminants *in vivo*. EOs have been utilized to alter rumen metabolism, leading to greater feed efficiency and increased animal productivity (Greathead 2003). Table 2 displays how EOs or their constituents changed rumen characteristics.

5 Effects of essential oils on the digestive system and the gut microbiota

Up to this point, we have looked at how EOs in the diet affects gut flora, enzyme function, and performance. EOs naturally arise to destroy harmful bacteria and stimulate beneficial bacteria like *Lactobacillus* spp., which regulates enzyme function and protects intestinal villi, and all without having any major practical effects on reaching a healthy body weight. Similarly, feed ratio transformation is typically improved upon (Dorantes-Iturbide et al. 2022). By enclosing low-molecular-weight peptides, a bacterial group called Lactobacilli has been shown to boost the enteric immune system, which in turn boosts resistance to disease and the immune system's ability to activate (Muir et al. 2000; Chandran 2021a). The rising numbers of Lactobacilli put up resistance against pathogenic bacteria by enhancing their receptor usage among themselves. Antimicrobial properties of EOs have been shown to prevent the attachment, colonization, and proliferation of *Escherichia coli*, *Clostridium perfringens*, and *Eimeria tenella* in the gut (Jamroz et al. 2006). Reducing the prevalence of pathogenic bacteria in the intestine and maintaining a healthy equilibrium between beneficial and harmful bacteria has been shown to enhance the epithelial cells' ability to revitalize the villus (Chandran 2021a; Benetel et al. 2022).

For livestock, the gut is a crucial organ used in the treatment of nutritional absorption. EOs mitigate the negative effects of oxidative stress on the digestive tract by supporting the health of the microorganisms that live there. Accordingly, improved intestinal health for absorption, which extends villus length and surface area in the gut, and increases growth and performance parameters, is crucial (Windisch et al. 2008; Franz et al. 2010; Zeng et al. 2015). In addition, digestive secretions like saliva, bile, mucus, etc., and enzymes like trypsin, amylase, lipase, etc., will increase incomplete infuriation of the epithelial tissues and decrease the depth of the crypts in the ileum. Increasing the time that food spends in the stomach has a positive effect on nutrient absorption (Platel and Srinivasan 2004; Chandran 2021a). A hypothetical explanation works perfectly to account for the discrepancy. However, approval for a range of EO types and concentrations is available. There is potential for making advantage of the wide range of bioactive component concentrations present in plants across parts, including those present in barks, leaves, flowers, etc. Complementary species and their range will be utilized as well. The content of the food, the amount of feed consumed, the level of hygiene practiced, and the state of the ecosystem are only a few of the environmental factors that influence how effective EOs are in boosting agricultural output (Brenes and Roura 2010; Poudel et al. 2019).

6 Antioxidant effects of essential oils

Many of the EOs also have antioxidant properties. The natural antioxidants found in EOs benefit animal health by reducing the effects of oxidative stress and the food industry by halting the oxidative processes that lead to spoilage. Using EOs as natural antioxidants is a fascinating area of study. This is because the dangers of synthetic antioxidants such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) to animals are contested. The ability to donate an electron to free radicals and the removal of the unpaired electron from the aromatic structure are the two main elements that govern the antioxidant processes of EOs (Fernandez-Panchon et al. 2008; Aziz et al. 2018; Hoffmann 2020). Sanchez-Moreno (2002) has found many techniques for assessing the antioxidant capabilities of phenolic components in EOs. Compared to vitamins E, C, and carotenoids, phenolics are described as being more powerful antioxidants. Essential oils alone or in association with other agents like cobalt have proven antioxidant activity and hence improve antioxidant capacity thereby lowering oxidative stress hence improving production performance (Lei et al., 2018; Seyidoglu et al., 2021).

There is a positive correlation between the degree of unsaturation of fatty acids and the oxidative damage caused by the lipids found in EOs (particularly phospholipids). In contrast, the polyunsaturated fatty acids (PUFAs) found in EOs help keep the permeability and fluidity of cell membranes. Hydroperoxides are formed when the proxy radicals in EOs combine with the polyunsaturated fatty acids, and these products then undergo a decomposition process to yield volatile non-radical aromatic chemicals. Animal products lose some of their nutritional content and spoil more quickly because of these chemicals (Pisoschi and Pop 2015; Poudel et al. 2019). There is a rising market for antioxidants that come from natural sources. Although some of them, like BHA, BHT, tert-butylhydroquinone (TBHQ), etc., are employed to postpone or halt the adverse consequences of lipid peroxidation in EOs, they do so by scouring the chain for peroxyl radicals. The diet of an animal plays a crucial role in inhibiting the development of free radicals in living organisms and their byproducts. Based on the nutritional safeguards and inferences of oxidizing stress, the optimal utilization of antioxidant levels in animal feed is proposed. The quality of meat and other animal products is improved when they are fed a diet containing both rosemary and oregano EOs (Amorati et al. 2013; Valdivieso-Ugarte et al. 2019).

Since EOs have more favorable redox characteristics and a more stable chemical structure, they are a rich source of natural antioxidants such as phenolic compounds. EOs have beneficial effects on the activity of antioxidative enzymes and prevent the generation of reactive oxygen species, two mechanisms by which they influence lipid metabolism in animal tissues. Depending on the concentration and nature of the EO, the membrane and organelle integrity of cells can be compromised (Bakkali et al. 2008; Aebisher et al. 2021). Incorporating EOs into one's diet is a straightforward and appropriate method of introducing natural antioxidants into phospholipid membranes, where they decrease oxidative reactions by preventing radical production and boosting their breakdown at localized regions (Govaris et al. 2004; Benetel et al. 2022).

7 Antimicrobial effects of essential oils

The use of synthetic chemicals aids in the prevention of spoiling and the spread of harmful germs in animal products. As a result of concerns over teratogenicity, carcinogenicity, acute toxicity, etc., the use of these substances has been curtailed. To this purpose, it was suggested that antimicrobial-containing animal products benefit from the addition of naturally occurring substances that improve their quality and longevity on store shelves (Faleiro et al. 2003). EOs are widely employed as functional chemicals in the pharmaceutical industry and for food flavoring (Corbo et al. 2009; Negi 2012). While most EOs are GRAS (Generally Recognized as Safe) ingredients, flavor concerns may prevent their widespread usage as food preservatives (Lambert et al. 2001; Leyva-López et al. 2017). EOs have proven antimicrobial effects (Evangelista et al., 2022). The antimicrobial effects of multiple bioactive compounds in EOs are not due to a single mechanism of action, but rather to the additive effect on many different boards in many different areas of the cell (Burt 2004; Ebani and Mancianti 2020). They influence zootechnical indices (Evangelista et al. 2022). It has been hypothesized that their efficacy is contingent on factors such as pH, chemical structure, concentration, or specific bioactive chemicals, in addition to the population and microbial species involved. They modulate gene regulation (Evangelista et al. 2022). Natural antimicrobials in food systems, including EOs, have been the subject of preliminary research into their antimicrobial effects (Brut 2004). The usefulness of EOs is reduced by the presence of lipids, water activity, pH, proteins, and enzymes, all of which are crucial components of food systems (Burt 2004; Sakkas and Papadopoulou 2017; Winska et al. 2019).

Since EOs are hydrophobic, they are useful in cleaving the lipid bilayer of mitochondria and bacteria, which results in changes to the cell's osmotic pressure due to disruptions in membrane integrity and ion transport systems. When the H^+ and K^+ ion gradients suddenly degenerate and the intracellular ATP pool depletes, it is easier to detect because of the fall in ATP production and a large amount of hydrolysis. Both the decrease in trans-membrane electric potential and the increased permeability to protons have an inhibitory effect on bacterial growth. When the bacterial tolerance limit is exceeded, cell death may occur as a result of a dramatic reduction in the concentration of essential chemicals and ions (Burt 2004). The transport of ions across the cytoplasmic membrane is disrupted due to a hydroxyl group in a phenyl ring and the ring's capacity to release its proton (Ultee et al. 2002; Burt 2004).

Disruption of the cell membrane, suppression of ATPase activity, and the release of intracellular ATP are just some of the antibacterial processes of EOs compounds including thymol, eugenol, and carvacrol (Brut 2004; Lambert et al. 2001). These substances tend to render the cell membrane permeable because they enter the phospholipid bilayer and form associations among the fatty acid chains (Ultee et al. 2000; Lambert et al. 2001). As a result, passive permeability increases as the membrane expands and becomes more brittle, and the fluidity of the membrane rises (Negi 2012). Hydrophobic binding of thymol to proteins in bacterial membranes alters their permeability. Gill and Holle (2006) reported that EOs inhibits ATP and ATPase activity inside *E. coli* O157:H7 and *Listeria monocytogenes* cells without causing any obvious changes to the membrane. Improved membrane permeability and cytoplasm leakage were also reported by Kim et al (1995), while Farag et al (1989) noted that cinnamaldehyde might interact with enzymes on the cell surface. These interactions can also lead to membrane distraction, impeding the diffusion of the proton motive force, or they can inhibit the activity of enzymes necessary for amino acid production.

Among the various secondary metabolites found in EOs, phenolic compounds have the strongest antibacterial activity. Consistent with their hydrophobicity, they primarily target the bacteria's cell membranes. Phenols alter membrane properties by rearranging lipid and protein components and stimulating the outflow of potassium ions. Catechins have been linked to liposome leakage due to the disruption of membrane integrity. Catechins and epigallocatechin gallate affect the outer polar area of lipid bilayers of the liposomes, which likely contributes to membrane rupture. Similar antimicrobial effects of vanillin were also demonstrated at the cell membrane and via cell inhibition in a variety of flora bacteria. Terpenes can also cross the membrane and alter the lipid structures' capacities. Phenolic chemical manipulation has been linked to the cell wall (Valdivieso-Ugarte et al. 2019; Winska et al. 2019).

Research has shown that EOs have antibacterial activity against both gram-positive and gram-negative bacteria, and this antimicrobial activity is quite potent (Panghal et al., 2011). It is well-accepted that EOs are slightly more efficient against gram-negative food spoilage bacteria and food-borne pathogens than they are against gram negative bacteria (Burt. 2004). Given that gram negative bacteria have an outer membrane enclosing their cellular wall, which confines the imposition of hydrophobic substances via lipopolysaccharide-protecting lipid bilayers, it stands to reason that they are more resistant to the action of antibacterials (Vaara 1992). Some studies with EOs have shown, however, that gram-negative bacteria can be more difficult to cultivate (Wilkinson et al. 2003). One of the most delicate bacteria is *Aeromonas hydrophila*. When added to Greek salad appetizers such as taramasalata and tzatziki, it was found that mint (*Mentha piperita*) EOs had a more potent antibacterial impact on *Salmonella enteritidis* than *Listeria monocytogenes* (Tassou et al. 1995). No significant difference in antimicrobial activity was found between gram-positive and gram-negative bacteria after 24 hours, while growth inhibition was typically prolonged to 48 hours with gram negative bacteria compared to gram-positive bacteria (Ouattara et al. 1997). There was no difference in susceptibility between gram-positive and gram-negative microbes in a report that tested 50 commercially available EOs against 25 taxa (Deans and Ritchie 1987). In a later investigation using newly distilled EOs, the same testing procedure and bacterial isolates were used, and it was found that gram-positive bacteria were more susceptible to two of the EOs tested, and equally sensitive to four others, compared to gram-negative ones (Dorman and Deans 2000; Valdivieso-Ugarte et al. 2019).

The antibacterial efficacy of EOs is dose-dependent. The effects of both room temperature and storage heat are detrimental. Also, the shape and arrangement of the tannins' ortho-phenolic hydroxyl groups can have a chilling influence on their organic effect. EOs are widely used as preservatives in a small number of food items. EOs of eugenol, coriander, clove, oregano, and thyme, when used at 5-20 µl/g, inhibited the growth of *Listeria monocytogenes*, *Aeromonas hydrophila*, and autochonous spoilage microbes in meat products, whereas oils of mustard, cilantro, mint, and sage were ineffective. Overly fatty meats may diminish the effectiveness of EOs. EOs of mint and cilantro were not as potent as they usually are in pate (30% fat) and a ham coating made of canola oil (Brochot et al. 2017; Rapper et al. 2021).

EOs can be used in food systems to minimize foodborne infections, hence extending the shelf life of animal products (Calo et al. 2015; Anand et al. 2022). Nutritional additions of EOs in animal feed aid in the establishment of natural microorganisms, which are then kept in the tissues. When combined at a concentration of 5-20 µl/g, mint oil prevented *Salmonella enteritidis* growth in low-fat yoghurt, among other dairy products. A rise in yoghurt starter culture species was observed when mint oil was employed at concentrations of 0.0.5-5 µl/g; however, cinnamon, cardamom, and clove oils were shown to have a more potent effect. EOs have been proven to be highly effective as food preservatives, and their implementation is anticipated on a wide range of food items containing a wide variety of ingredients (Cannas et al. 2016; Valdivieso-Ugarte et al. 2019; Rapper et al. 2021). Figure 3 provides evidence of the effectiveness of EOs against bacteria and other pathogens.

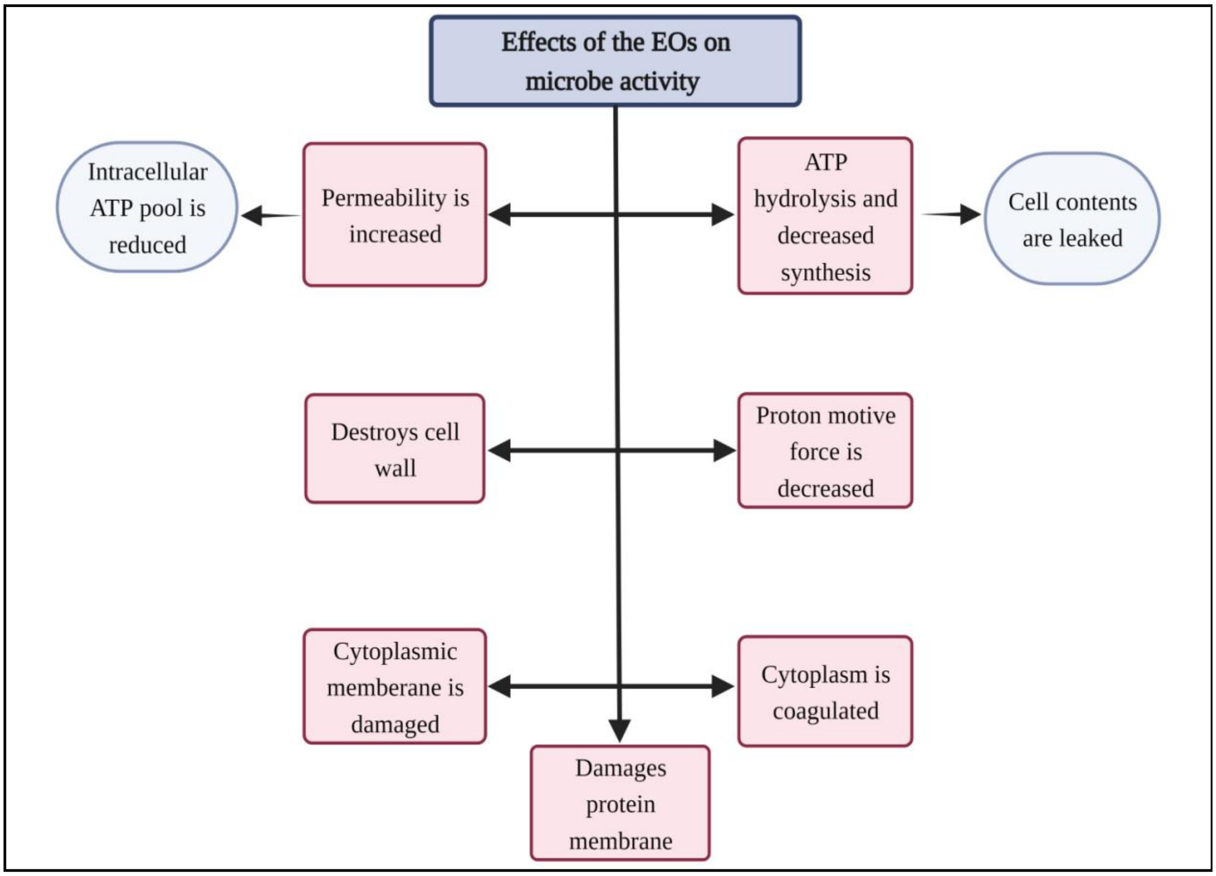

Figure 3 Anti-microbial effects of essential oils in livestock

8 Inflammation reduction by essential oils

When body tissues are harmed or infected, they trigger a physiological response known as inflammation. The production of cell adhesion molecules and the release of pro-inflammatory cytokines are both triggered by inflammation, which in turn increases the permeability of mucosal endothelial cells (Sandner et al. 2020). EOs have shown antiinflammatory nature in animal studies (Schabauer et al. 2017). They can have direct or indirect anti-inflammatory actions via immunomodulatory or counter physiological and inflammatory mechanisms including hyperemia and blocking synthesis and secretion of inflammatory mediators (Nehme et al. 2021). As a result of their antioxidant properties and their ability to signal through regulatory transcription factors called cytokines, EOs can influence the expression of both anti-inflammatory and pro-inflammatory genes. Hyperemia, for example, will increase leukocytes and anti-inflammatory actions while also blocking the secretion and synthesis of inflammation mediators like nitric oxide, histamine, and pro-inflammatory cytokines, acting at multiple levels to reduce inflammation (Asif et al. 2020).

EOs have been used for quite some time for their immunomodulatory effects on human patients. *Lavandula angustifolia* serves as an example due to its anti-inflammatory properties, since it can promote phagocytosis and lower the pro-inflammatory cytokinins (Giovannini et al. 2016). Even though there is less information on the degradation rate of EOs and their constituents in the gastrointestinal tract and how they should be prepared and fed to animals, interest in their use continues to rise. Previously, it had been established that in *Mollugo verticillata* EO can lower the number of bacteria in the glands of test mice infected with Enterococcus faecium, suggesting that EOs will enhance immunity to lessen inflammation. Inflammation of the mammary glands, often known as mastitis, is common and can be very expensive to treat. Most cases of mastitis are brought on by an intramammary infection caused by bacteria or other microbes. Bovine mastitis describes bladder irritation in cattle (Salehi et al. 2018; Chandran and Radhakrishnan 2019; Sandner et al. 2020; Chandran 2021a; Chandran and Athulya 2021). The infection of the udder by viruses, yeast, or bacteria causes this disease (Chandran 2021b; Anand et al. 2022). Mastitis and mammary gland infection occur when a pathogen invades the milk supply and multiplies beyond the control of the teat canal barriers. If the immune system is overworked or compromised during parturition, or if the pathogen can evade it, the resulting mastitis is chronic or severe. However, if the immune system can mount an effective

Table 3 Effectiveness of various EOs in treating bovine mastitis

Plant	Use
Cymbopogon citratus	Shows high antimicrobial activity in every type of bacteria
Minthostachys verticillata	Inhibits all bacterial isolates' growth
Origanum vulgare	Showed active antimicrobial activity; Somatic cells are reduced and *E. coli* was not present in milk
Copaifera spp.	Reduced antimicrobial activity
Origanum floribundu	Exhibit high anticandidal activities
Cymbopogon citratus	Exhibit satisfactory antimicrobial activity
Alpinia zerumbet	Strains showed extreme sensitivity to EOs at 100mg/mL
Cinnamomum zeylanicum	Exhibit high inhibiting action against the bacterial strains
Syzygium aromaticum	High antimicrobial activity and biofilm formation is affected
Eucalyptus globulus	Has shown small inhibitory actions in time
Thymus vulgaris	Effective against algal strains

Source: Reshi et al. (2017); Valdivieso-Ugarte et al. (2019); Sandner et al. (2020); Chandran (2021a)

defense, the resulting mastitis is just temporary and mild (Chandran et al. 2021a; Chandran et al. 2021b; Lejaniya et al. 2021a; Lejaniya et al. 2021b; Sharun et al. 2021).

The fundamental benefit of EOs is their all-natural nature, as long-term use of conventional medications will have resulted in resistance (Chandran et al. 2022). *Terminalia chebula* ethyl acetate extract has been shown to have antibacterial activity against milk bacteria associated with subclinical mastitis, and similar activity to amoxicillin (Chandran and Arabi 2019). *Sanguisorba officinalis* ethanolic extract is used in traditional Chinese medicine and has been shown to prevent the biofilm formation of *Staphylococcus aureus* and methicillin-resistant strains of the bacteria. Vaseline in EOs has potent antibacterial properties, as evidenced by its ability to speed up wound healing by a factor of 100 when combined with thymus EO (Reshi et al. 2017; Sandner et al. 2020). Excitingly, the extracts led to noticeable improvement after treatment. *Adiantum capillus*, also known as *Fumaria indica*, has been shown to produce excellent clinical results. Plants with these properties are employed as adjuvants in antimicrobial treatment, specifically for the treatment of cow mastitis (Valdivieso-Ugarte et al. 2019). Table 3 might help us learn more about the effectiveness of EOs in treating bovine mastitis.

8.1 Limitations in using essential oils for inflammation

When using EOs for medical purposes, there are a few caveats to keep in mind. The mix of secondary metabolites, responsible for the plant's medicinal and biological capabilities, will change according to environmental parameters such as climate management, phenological stages, and soil (Burt 2004; Andrade et al. 2017). The use of EOs as a substitute for mastitis also faces the challenge that their commercial scale manufacturing will require a substantial volume of plant biomass. We should also evaluate the antimicrobial activity of the EOs to compare and utilize it because the different methods of application used will have different impacts, so this is a time-consuming task that needs careful consideration before being undertaken (Amber et al. 2018; Valdivieso-Ugarte et al. 2019). Clinical applications in livestock can be appropriate after proper in vivo evaluation in experimental animals.

9 EOs in animal nutrition

EOs and their bioactive components play an important role in the feed industry because of their perceived safety. *In vivo* results suggest that EOs are included in animal diets as a natural means of promoting growth. The quality of meat and milk can also enhance by the use of EOs in animal feeds. Meat quality, shelf life, and even antioxidant activities like reduced lipid peroxidation can sometimes be improved by feeding animals low dosages of EOs (between 1.33 and 4 g/animal/day). Oxidation proteases in EOs improve meat softness. 3.5 grams of EOs per animal per day is the standard recommendation for feedlot cattle (Rivaroli et al. 2016; Chandran et al. 2019; Chandran 2021a). But a pro-oxidant impact is caused by higher concentrations of EOs, which is harmful to the health of animals. This occurs because mitochondrial permeabilization can be induced by large doses, causing an alteration in electron flow and a subsequent increase in free radical production within mitochondria. Absorption, distribution, metabolism, and excretion (ADME) theory does not evaluate the transfer of metabolites from one component of EOs to another to determine whether or not EOs improve meat quality when fed to animals. As a result, many studies cannot attribute changes in meat quality to the direct or indirect impacts generated by multiple chemicals in EOs at the meat level (Omonijo et al. 2018;

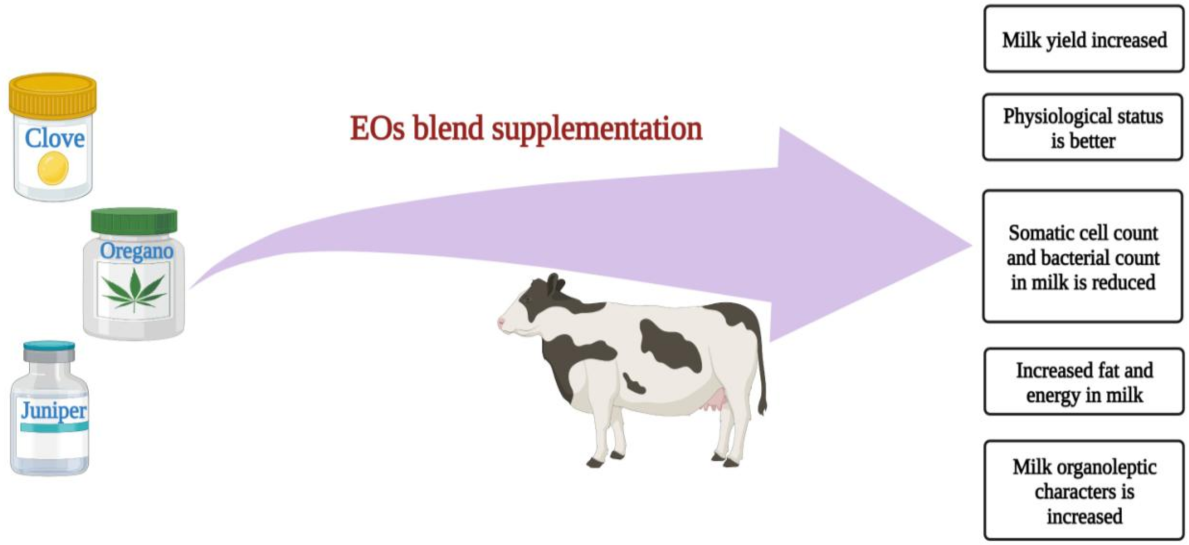

Figure 4 Impact of a feed supplement containing essential oils on dairy cow productivity

Valdivieso-Ugarte et al. 2019; Nehme et al. 2021). Al-Suwaiegh et al. (2020) showed that early lactation Holstein dairy cows fed modest dosages of an EOs blend consisting of clove, juniper, and oregano in the same proportion had an increase in milk total bacterial and somatic count, yield, and feed efficiency. Because EOs in low doses does not affect microbial populations in the rumen, this is the case. Milk production is not affected by giving a blend of EOs to eight lactating sheep, but the resulting fermentation is (El-Essawy et al. 2021). Figure 4 shows how the EOs blend affected the productivity of dairy cows.

The rosemary EOs in the diet has improved the lamb's flavor and aroma. It has been revealed by El-Essawy et al. (2021) that adding Thymus EOs to the diet of dairy cows does not enhance the fermentation process. Soltan et al. (2018) created a blend of EOs that had a suppressing effect on methane generation in Santa Ines sheep. The blend included eugenol, capsicum oleoresin, carvacrol, and cinnamaldehyde. EOs given to animals might affect the monetary worth of their meat and milk by inhibiting the microbes responsible for the bio-hydrogenation of unsaturated fat. Feeding dairy goats with EOs including nails, clove, anise, and juniper increases their levels of omega-3 and conjugated Linoleic Acids (Morsy et al. 2012; Prakash et al. 2021a; Prakash et al. 2021b; Kumari et al. 2022). Kholif et al. (2018) found that supplementing Farafra ewes with a mixture of thymus and capsicum EOs and fibrolytic enzymes increased their milk yield, fat content, and feed efficiency. Fiber digestibility is improved by this EO blend because it promotes the growth of cellulolytic bacteria, which in turn raises the amount of fat stored by the animal. There are positive results for total protozoa when EOs like linalool, diallyl disulfide, and alpha-pinene are used in animal feed for more than 70 days. Serum metabolite data show that EOs improves the antioxidant status of small ruminants' blood.

10 Conclusion and future prospects

Scientists are interested in EOs and its components not just because they are antibacterial, but also because they kill insects, viruses, toxins, fungi, and parasites. The enhanced biological activity of EOs as antioxidants, antibacterials, and antifungals provides them an edge in these industries. During and immediately following flowering is the best time to gather herbs for extracting their EOs, as this is when the EOs will be at their most potent against microbes. Supplementing ruminants' diets with EOs, both singly and in various combinations, had no effect on food intake, daily procurement rates, or total volatile fatty acid concentrations, according to the major observation. Consequently, rumen methanogenesis benefits are not universally convincing. A possible explanation is that bacteria in the rumen have the potential to transform and break down EOs. Some of the factors that will determine how effective EOs are in boosting agricultural output include dietary diversity, feed consumption rates, sanitation practices, and environmental health. Nutritional supplementation with EOs is a practical and efficient way to introduce natural antioxidants into phospholipid membranes, where they decrease oxidative reactions by preventing the production of radicals and boosting their breakdown at localized regions. EOs are very effective as food preservatives, and their incorporation into a wide range of food items and formulations is anticipated. The antibacterial and anti-inflammatory properties of EOs found in plants are utilized as adjuvants to treat bovine mastitis. Feed efficiency, yield, and the number of bacteria and somatic cells in milk all go up. This is because EOs in low doses do not affect microbial populations in the rumen. In addition to their other beneficial properties, EOs and their constituents are potent anti-inflammatories, anti-microbial, and immune system boosters. As feed additives, these chemicals are safe to consume.

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