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Essential oils as valuable feed additive: A narrative review of the state of knowledge about their beneficial health applications and enhancement of production performances in poultry

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ABSTRACT

New research has begun to develop safe and effective alternatives to feed-antibiotics as growth enhancers in response to mounting pressure on the poultry sector to do so. There is a significant demand for poultry products all across the world right now. To achieve this goal, key performance indicators are optimized, such as the rate of chicken growth, the amount of feed used, and the health of the flock as a whole. As a result of this growing need, various alternatives to antibiotics have entered the market. New approaches are desperately needed to keep poultry productivity and efficiency at a high level in the face of mounting pressure to limit the use of antibiotics. Recent years have seen an uptick in interest in the potential of aromatic plant extracts as growth and health boosters in poultry. The great majority of plants' positive effects are accounted for by essential oils (EOs) and other secondary metabolites. EOs have been proven to promote digestive secretion production, improve blood circulation, exert antioxidant qualities, reduce levels of dangerous microbes, and maybe improve the immune status of poultry. EOs are often believed to be safe, non-toxic alternatives because they are all-natural, chemical-free,

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and devoid of potentially harmful deposits. EOs are extracted from plants, and while there are thousands of them, only approximately 300 have been deemed to have significant commercial value. Many different types of bacteria, viruses, fungi, and parasites are negatively affected by EOs in multiple studies conducted both *in vitro* and *in vivo*. The review covers the fundamentals of EOs, their anti-oxidant and immunomodulatory capabilities, their growth-promoting benefits, and their effectiveness against numerous diseases in poultry.

1 Introduction

Preventative antibiotic usage in chicken nutrition is commonly accepted as an effective strategy for maximizing growth, feed consumption, feed utilization, and decreasing mortality from clinical diseases. Fears that antibiotic-resistant microbes will spread across the food supply prompted the European Union (EU) to ban their use in cattle and poultry in 2006 (Chandran and Arabi 2019; Chandran et al. 2019; Aebisher et al. 2021). Therefore, novel plant-based commercial additives, such as aromatic plant extracts and their refined constituents, have been studied for their possible application in future feed alternatives. Due to their lack of residue and widespread acceptance as safe for use in the food business, such products provide several benefits over conventional antibiotics (Chandran 2021a; Chandran 2021b; Chandran and Athulya 2021; Chandran et al. 2021a; Saleena et al. 2021a; Saleena et al. 2021b; Sharun et al. 2021; Uddin et al. 2021; Alajil et al. 2022). In the past decade, these herbs have come under scrutiny for their potential as animal development performance boosters. Since the 1990s, the demand for natural supplements that boost the growth and production performance of poultry has grown (Amorati et al. 2013; Alagawany et al. 2015; Yadav et al. 2016; Dhama et al. 2018; Tiwari et al. 2018; Chandran 2021a; Chandran et al. 2021b; Chandran et al. 2022; Kumar et al. 2022a; Kumari et al. 2022a; Kumari et al. 2022b).

Aromatic plant liquids called essential oils (EOs) are extracted from certain parts of plants. Ethereal oils and volatile oils are two other names for these substances (flowers, buds, seeds, leaves, twigs, bark, herbs, wood, fruits, and roots). Secondary plant metabolites called terpenes and low-boiling phenylpropenes are the building blocks of EOs. Quinta essentia, or "herbs and spices," refers to five specific plant essences that have become synonymous with them (Hoffmann 2020; Leherbauer and Stappen 2020; Nehme et al. 2021). Normal extraction procedures involve distillation, most frequently steam distillation. Around 300 EOs are considered to be commercially significant, most of which are employed in the flavoring and fragrance industry. Scientific experiments conducted over the past three decades have confirmed a plethora of positive benefits in addition to those traditionally stated. Their anti-inflammatory capabilities, antibacterial characteristics, antioxidant strength, and capacity to induce digestion are just a few of their many useful attributes in poultry nutrition (Abd El-Hack et al. 2016; Andrade et al. 2017; Omanijo et al. 2018; Alajil et al. 2022; Buttar et al. 2022).

EOs can be extracted from a wide variety of aromatic herbs and spices, including mugwort (*Artemisia vulgaris*), peppermint (*Mentha piperita*), oregano (*Origanum vulgare*), lemon balm (*Melissa officinalis*), onion (*Allium cepa*), fennel (*Foeniculum vulgare*), sage (*Salvia officinalis*), rosemary (*Rosmarinus officinalis*), turmeric (*Curcuma longa*), and many others (Calo et al. 2015; Zeng et al. 2015; Dosoky and Setzer 2018). Even though steam distillation is not the only method used to acquire Eos for commercial reasons, it is by far the most common. Other methods include fermentation, extraction, and expression (Sakkas and Papadopoulou 2017). In addition to dissolving in organic solvents, the EOs also have a distinct aroma. Most EOs are lighter than water because their specific gravity is between 0.80 to 1.17. These oils are sensitive to heat and light, so keep them in dark, cool bottles (Brochot et al. 2017; Pandey et al. 2017). EOs are volatile chemical compounds that are synthesized as secondary metabolites in aromatic plants. Their pungent aromas serve as a distinguishing feature because they are accountable for the aromatic plant's traits. EOs are often lipid- and organic-solvent-soluble, lubricious, and volatile. We can find them in different parts of plants, such as buds, blossoms, leaves, seeds, stems, flowers, fruits, roots, wood, and bark (Brenes and Roura 2010; Oussalah et al. 2006; Leherbauer and Stappen 2020). EOs can be extracted by a wide variety of processes, like solvent extraction, steam distillation, and supercritical fluid extraction (Valdivieso-Ugarte et al. 2019). It is possible to gain insight into the qualities and mechanism of action of EOs by studying their biochemical composition. EOs can have a wide range of chemical compositions, with their major components potentially being an aromatic, aliphatic, or terpenic sequence (Pandey et al. 2017). Some examples of these components are esters, phenols, terpenes, aromatics, volatile acids, ketones, and aldehydes. After harvest, it is not necessarily necessary to process or treat the plant part that underwent hydrokinetics. Except for dry ingredients like lavender, cinnamon, and lime blooms, fresh plants added to solutions have a greater medicinal impact and a more pleasant aroma (Rapper et al. 2021; Raza et al. 2022).

The increasing demand for EOs and other plant extracts can be attributed to the fact that they are following modern thoughts about the future of agriculture in the European Union and with consumer preference for natural products. Moreover, their beneficial characteristics may be used as a treatment for a variety of illnesses (Plant et al. 2019). There are reports that some EOs can kill microorganisms. Because of their antimicrobial properties, EOs have also been studied as suitable feed additives. In addition to their antibacterial actions, EOs or their components have been shown to have hypolipidemic, antioxidant, digestive stimulant, antiviral, antimycotic, antioxidant, antiparasitic, and insecticidal activities. Perhaps the function of these compounds in plants is related to these characteristics (Giovannini et al. 2016; Asif et al. 2020). However, many herbs and spices are used as condiments in many different dishes. Garlic and chili pepper EOs and oleoresins, as well as cinnamic aldehyde, carvacrol, and pipperine (from black pepper), have all been used for centuries to enhance the flavor of food. While some studies have indicated that adding herbs and botanicals to chicken feed increases feed intake and thus the animals' growth rate, others have found no such conclusive results (Cannas et al. 2016; Aziz et al. 2018; Asif et al. 2020; Sasi et al. 2021).

The purpose of this paper is to provide a synopsis of the literature on the use of EOs and their constituents in poultry nutrition and to discuss the possible mechanisms of action for these compounds. The current state of knowledge on possible antagonistic and synergistic effects is presented, and future directions for research are recommended.

2 Chemical composition and bioactive compounds in EOs

It is believed that the activity of extracted volatile oils is connected to the specific chemical make-up of each oil, as well as its functional groups, potential synergistic interactions between components, concentrations, and other factors. The chemical complexity of EOs varies according to their source, climate, and plant type (Martinez et al. 2006; Cannas et al. 2016). According to this hypothesis, different behaviors emerge as a result of different changes to an EO's underlying structure. Sterols, triterpenes, alkaloids, tannins, flavonoids, and a variety of other naturally occurring medicinal compounds have all been described (Eslahi et al. 2017). Terpenes, a class of secondary metabolites, were synthesized via the head-to-tail paradigm by joining together isoprene units with a 5-carbon base (C5) or 2-methyl-1,3-butadiene. Terpenes, which come in a wide variety of groups, are various combinations of isoprenes that differ in structure and function (Rubio et al. 2013). Terpenes can be found all over the natural world. They can be found in plentiful supplies and have low-priced raw materials. Herbivores are discouraged from grazing on plants by monoterpenes in the air, which also acts as an antifungal defense (Langenheim 1994; Sakkas and Papadopoulou 2017). Specifics on the various plant types that contribute to essential oils and their chemical compositions are presented in Table 1.

Table 1 Specifics on the various plant types that contribute to essential oils and their chemical compositions

Plant source	Scientific name	Main components in EOs	References
Bergamot	*Citrus bergamia*	Limonene Linanine Linalool	Nabiha et al. (2010); Zhai et al. (2018)
Black pepper	*Piper nigrum*	Piperine Piperoleine Piper amide	Singh et al. (2005); Zhai et al. (2018)
Carrot	*Dacus carrot*	Carotol Sabinene Beta caryophyllene Alpha pinenne	Ma et al. (2015)
Cinnamom	*Cinnamomum verum*	Trans cinnamaldehyde Limonene Eugenol	Baratta et al. (1998); Abd El-Hack et al. (2022)
Clove	*Syzgium aromaticum*	Eugenol Eucalyphol	Naveed et al. (2013); Zhai et al. (2018)
Cumin	*Nigella sativa*	Thymoquinone p-cymene Alpha-thugene	Singh et al. (2014)
Eucalyptus	*Eucalyptus* spp	1,8-cineole Cryptone Alpha-pinene	Elaissi et al. (2012); Abd El-Hack et al. (2022)
Fennel	*Foeniculam vulgare*	Trans-anethol Frenchone Methyl cavicol	Hoffmann (2020)
Lime	*Citrus aurantifolia*	Limonene Beta-pinene Alpha-terinine	Costa et al. (2014); Zhai et al. (2018)

Since monoterpenes can include a broad variety of components—hydrocarbons such as p-cimene, camphene, and myrcene, as well as alcohols such as menthol, borneol, and linalool—they are the most versatile structural kinds in EOs. Geraniol and citronellol are aldehydes; camphor, pulegone, and carvone are ketones; linalyl acetate, citronellol acetate, and menthyl are esters; menthofurane and 1,8-cineole are ethers; menthofurane and ascaridole are peroxides; carvacrol and thymol are phenols; and so on (Pavela 2015). Aromatic compounds like terpenes are more common than their aromatic counterparts. These compounds are found in many different plant species, including sassafras, tarragon, parsley, fennel, star anise, nutmeg, and many more. As with phenylpropane, these compounds are often present in lower concentrations than terpenes (Asif et al. 2020; Sharifi-Rad et al. 2021). Plants normally use different biosynthetic pathways to produce terpenes and phenylpropanic derivatives, while there are exceptions. Applications for aromatic compounds are comparable to those for sesquiterpenoids and monoterpenoids. Alcohols, aldehydes, phenols, methoxy compounds, and methylene derivatives are all in this category (Eslahi et al. 2017; Khan et al. 2022). The most common type of terpenoids in EOs is monoterpenes, which can make up as much as 90% of the total and have a very soothing, subtle aroma. A monoterpene consists of two isoprene units, or 10 carbon atoms (Puvača et al. 2022). Numerous terpene synthases monitor the synthesis of monoterpenes. Like monoterpenes, sesquiterpenes can be synthesized by the enzyme sesquiterpene synthase from farnesyl diphosphate, but the structural variety of sesquiterpenes is far larger than that of monoterpenes. Plants have been found to contain these enzymes, which are essential in the creation of sesquiterpenes (Fattahi et al. 2016; Aziz et al. 2018). The chemical composition and structure of major bioactive compounds present in EOs are responsible for their beneficial health effects (Figure 1).

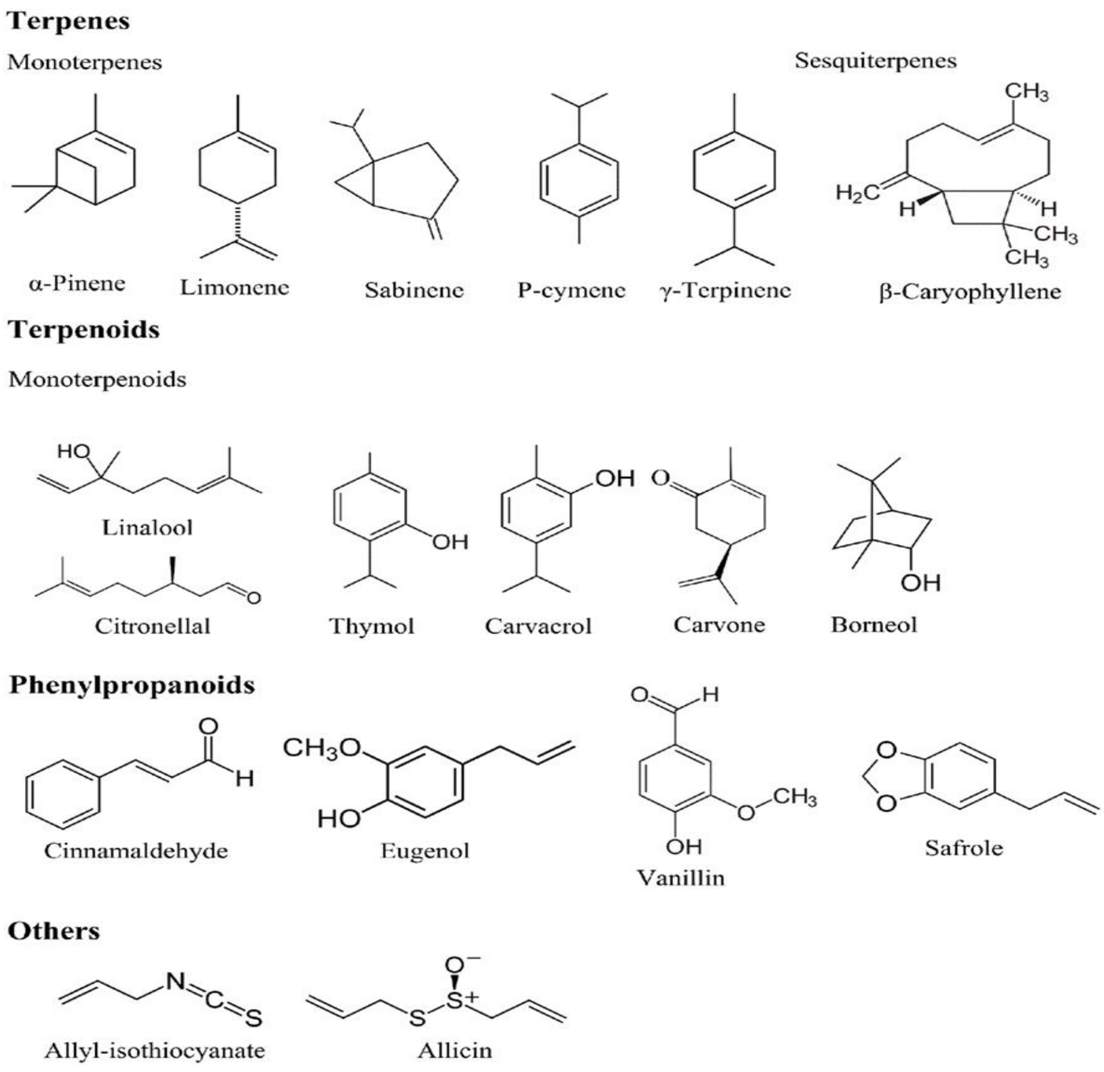

Figure 1 Structure of major bioactive compounds responsible for potential health benefits of essential oils

Fragrant EOs are often colorless or yellowish liquids that can be easily ignited. The viscosity of most Eos is comparable to that of water or alcohol, while others can be rather thick. Aromatic EOs are sometimes misunderstood because of their misleading name, which suggests that they are composed of fats or oils. Unlike water, EOs completely dissolve or almost completely dissolve in all organic solvents. Eos get thicker, darker, and more acidic when exposed to air for extended periods (Sakkas and Papadopoulou 2017; Chandran 2021a; Kumar et al. 2022b). It is challenging to determine the boiling point of these complex mixtures due to the large number of chemicals involved; nonetheless, fractional distillation is effective at separating these compounds because their boiling temperatures often fall within the range of 150 to 280°C (Pandey et al. 2017; Omonijo et al. 2018). EOs from various plant species can include anywhere from 20 to 60 different biologically active compounds, with only a subset (20-70%) playing a significant role and the rest present only in minute quantities. It is possible for there to be a big difference in the amount of biologically active substances present depending on the plant parts utilized, the season they were collected, and the region they were cultivated (Hoffmann 2020; Puvača et al. 2022).

3 Potential beneficial effects of EOs on the health of poultry

The major potential benefits of EOs on the health and production of poultry are depicted in Figure 2.

3.1 Effect of EOs on feed intake, feed utilization, and growth performance

According to Zhang et al. (2014), EOs are used as growth enhancers in poultry feed because of their stimulating effect on poultry health and production (Amad et al. 2011). *Origanum vulgare*/ *O. heracleoticum* is a member of the Lamiaceae family of plants and is the accepted scientific name for this herb. The phenolic chemicals found in the oils of this plant are plentiful (69.55% carvacol and 4.09% thymol respectively). Monoterpene hydrocarbons, including cymol, are also mentioned (Mathlouthi et al. 2012; Aziz et al. 2018; Salehi et al. 2018). In comparison to birds on a basal diet, the oregano EO in those birds given a high-fat diet had more growth. Synergy essence, a commercial product containing oregano EO (500g/ton), decreased lipid peroxidation in minced chicken breast (Bozkurt et al. 2014a). Recent studies have shown that including EOs in a broiler's diet causes the birds to consume less because of the EOs' offensive odor, which makes the feed less palatable and may cause the birds to stop eating altogether (Bozkurt et al. 2014b; Leyva-López et al. 2017; Hoffmann 2020).

Feed intake was shown to be reduced in birds given 10 g/kg of oregano herb, but was equal in birds given 1 g/kg oregano EO. Both the rosemary EO-supplemented and control groups consumed the same amount of feed. Feed intake was also shown to rise significantly when either oregano EO (300, 500, or 700 mg/kg) or

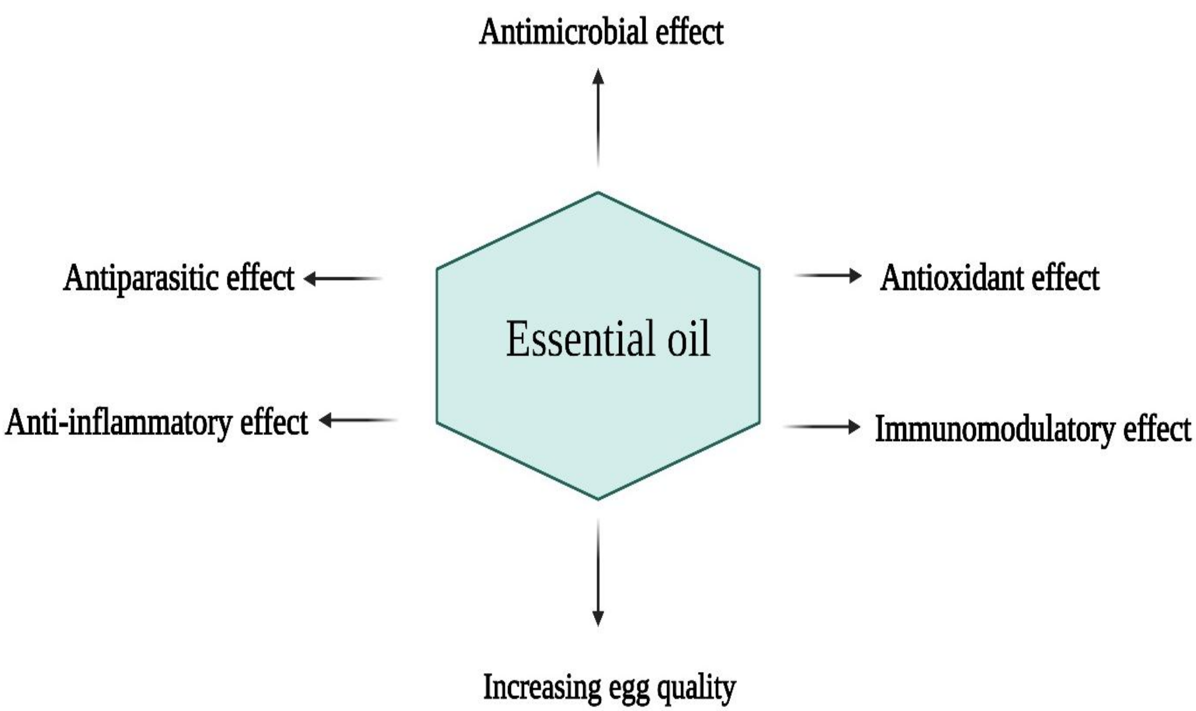

Figure 2 Potential health and production benefits of essential oils in poultry

thyme EO (100, or 200 mg/kg) was added to the feed (Faleiro et al. 2003). Feasting poultry on a diet containing 100 mg/kg of the drug did not influence the birds' food consumption. Poultry fed EOs at 25 or 50 mg/kg demonstrated no observable effects on feed consumption (Jang et al. 2007; Prakash et al. 2021a). Supplementing the diet with 18 mg/kg of oregano, eucalyptus, thyme, and cinnamon EO led to an increase in daily feed consumption (Leyva-López et al. 2017). EOs were thought to have improved feed intake as a whole by helping the gut microbiome return to a more stable state. The feed intake of broilers improved after the EO blend of oregano, anise, and clove was given to their diet at 200 and 400 mg/kg for three weeks (Yitbarek 2015). Potentially responsible for the enticing impact of the EO blend and, thus, the increased feed intake, are chemicals like carvacrol, thymol, anetole, and eugenol (Prakash et al. 2021b).

Thymol is a herb used as a feed additive for livestock, fish, and poultry. It improves performance indicators and feed utilization through structural activation and alteration in the digestive system, among other methods. Strong antibiotic action has been shown in vivo and/or in vitro to improve nutrient absorption and metabolism, alter gut flora and prevent harmful chemicals and free radicals from interacting with cellular biological components (Faleiro et al. 2003; Leherbauer and Stappen 2020). Microorganisms with antibiotic resistance, including methicillin-resistant *Staphylococcus aureus* (MRSA), are present in a wide variety of pathogens (bacterial, viral, fungal, and parasitic) (Lejaniya et al. 2021a; Lejaniya et al. 2021b; Kumari et al. 2022a). Coccidiostat medications are effective against helminths and leishmaniasis. The bacterial enterotoxins A, B, and hemolysin produced by several *Staphylococcus* spp. can be inhibited by thymol. Feeding broiler chicks with thymol was found to have no significant influence on growth performance metrics such as ileal content of microbiota, live body weight, and feed utilization, suggesting that it could be explored as a unique and new medicinal chemical that combats leishmania (Ezzat et al. 2016; Giovannini et al. 2016). The anticoccidial effect of EOs in poultry is depicted in Figure 3.

Certainly, adding EOs to the poultry diet has many advantages, but their use is also accompanied by some issues and restrictions. Following their botanical origin, environment, harvest season, and procedures, they may differ greatly in extraction, drying, and storing, which caused inconsistent results to be reported. Some EOs, like carvacrol, have a very strong flavor and odor, which may cause them to alter feed intake in an unfavorable way, which may account for the contradictory results of studies examining the effects of adding EOs to chicken diets on performance metrics (Fernandez-Panchon et al. 2008; Basmacioglu Malayoglu et al. 2010). Mists of EOs like peppermint and thyme are safe for broilers, and peppermint EO may even improve performance metrics and have a major effect on broilers' immune systems. There is not enough evidence in the literature to support the use of EO mists as growth and health boosters. Additional research into the mechanisms of immunological response in broilers exposed to varying concentrations of EO mist under real-world conditions was emphasized by the cited authors (Giovannini et al. 2016; Sandner et al. 2020). EOs of oregano, rosemary, sage, thyme, and yarrow

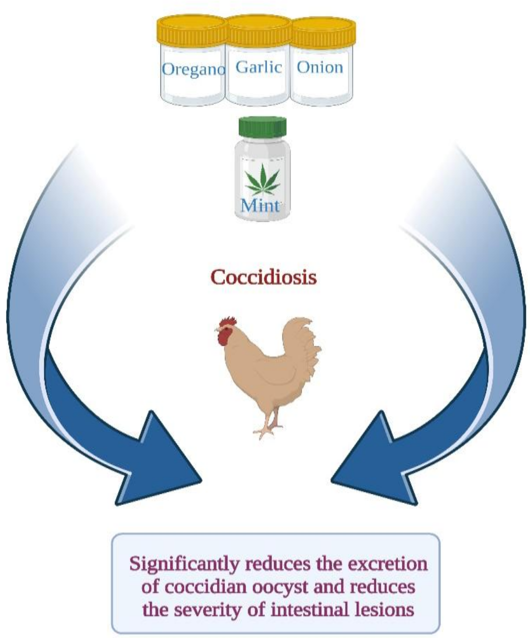

Figure 3 Anticoccidial effect of essential oils in poultry

have been found to improve the health performance parameters of animals, such as increasing egg weight, body weight gain, feed intake, and feed conversion ratio. Sage and garlic EOs, as well as those containing cinnamic aldehyde, thymol, and carvacrol, are immunostimulatory and beneficial to gut microbes. The improvement in animal welfare and hygiene following EO fumigation of chicken houses raises the possibility that EOs can be employed as air disinfectants to get rid of respiratory pathogens (Greathead 2003; Hoffmann 2020; Mucha and Witkowska 2021; Kumari et al. 2022b).

There are undoubtedly many benefits to using EOs in poultry diets and water, but their usage is also associated with some challenges and constraints. Extraction, drying, and storing methods might vary widely according to the plant species, region, harvest season, and other factors, leading to conflicting findings (Salehi et al. 2018; Sharma et al. 2019). The overwhelming aroma and flavor of some EOs, such as carvacrol, may unfavorably alter feed intake, which may explain why studies on the impact of adding EOs to poultry diets have yielded conflicting results (Windisch et al. 2008; Sharma et al. 2019). EO mists, such as those made from peppermint or thyme oil, have no negative impacts on the health of broilers, may improve performance indicators, and have a substantial impact on the immune systems of broilers. As the aforementioned authors emphasized, more study is needed to determine the precise immune response pathways in broilers exposed to varying concentrations of EO mist (Brenes and Roura 2010; Plant et al. 2019). Egg weight, feed conversion ratio, and feed intake are just some of the metrics that have been shown to improve with the addition of EOs from herbs including thyme, oregano, sage, rosemary, and yarrow to the diet. EOs of sage and garlic, as well as those containing cinnamic aldehyde, thymol, and carvacrol, have been shown to have probiotic or immunostimulatory effects. Because of the positive results seen after using EOs to fumigate chicken coops, it is possible that these compounds can be used as air disinfectants to eliminate respiratory infections (Mucha and Witkowska 2021; Chandran et al. 2022). Critical factors affecting the usefulness of essential oil as a chicken feed is presented in Table 2.

3.2 Effect of EOs on feed conversion efficiency

The effects of EOs on chicken production have been proven in several types of research. Their research indicates that EOs can increase weight gain, feed intake, and feed conversion by 2.0%, 0.9%, and 3.0% in piglets, and 0.5%, 1.6%, and 2.6% in poultry (Zeng et al. 2015; Puvaca et al. 2020). Experiments were designed to prove that supplementing broiler feed with 200 ppm of oil extract (cinnamon and thyme) led to a significant increase in feed conversion ratio and weight over six weeks. The ratio of high-density lipids to cholesterol in the blood was also lowered. Herbal plant oils may, then, be useful for boosting poultry output by encouraging faster growth and better digestion.

Anise is the common name for the plant *Pimpinella anisum* L. It is frequently grown in countries like Pakistan, Iran, Turkey, India, and others due to its pleasant perfume and suitable climate. Anethole, along with estragole, eugenol, methyl chavicol, and anisaldehyde, is its active ingredient. The feed conversion ratio (FCR) was shown to be elevated by 12% when anise EO was administered at a dose of 400mg/kg (Bakkali et al. 2008). However, when administered at 100 and 200mg/kg, thyme oil improved the meal conversion ratio. Broiler hens were used in an experiment to measure the effectiveness of thyme oil. There was

Table 2 Critical factors affecting the usefulness of EOs as a poultry feed

Influencing factors	Essential oils / their critical components	Results	References
Dietary composition	Thymol Cinnamaldehyde	Reduced EO effectiveness may be seen with a more easily digested diet	Lee et al. (2003); Abd El-Hack et al. (2022)
Chemical makeup of essential oils	Thyme Oregano Marjoram Rosemary Yarrow	Changes in terpene makeup may account for why different EOs and botanicals produce varying effects	Cross et al. (2007); Abd El-Hack et al. (2022)
Dosage	Oregano	Oregano supplementation induced a quadratic response in feed consumption and weight gain	Abdel-Wareth et al. (2012)
Environment	Caraway Fennel	Fennel and caraway oil appear to alleviate stomach distress	Lee et al. (2003); Zhai et al. (2018)
Age of poultry	Oregano	Oregano oil's effects are minimal at the elite level, but they could be enhanced at lesser levels of competition.	Botsoglou et al. (2002); Zhai et al. (2018)

significant weight gain, an improved feed conversion ratio, a rise in livability, and a rise in turnover in a broiler production system when 100 mg/kg of thyme oil is incorporated into poultry feed (Aziz et al. 2018). *T. vulgaris* is grown for its medicinal properties and also as a spice crop around the world. Extreme heat and dry conditions bring up a widespread appreciation for this herb. This plant's EO is stored in its glandular hairs in a variety of chemical forms and formulas, and it has the unique feature of evaporating in the presence of injury to those hairs. It is the potent fragrance that draws people to the plant, where they can then harvest the oil for use in a variety of applications. Extractions of thyme oil contain between 20 and 55% of the active components namely thymol and carvacol (Wade et al. 2018; Chandran 2021a).

Antioxidant nutrients like polyunsaturated fatty acids (PUFA) are recommended for use in animal feed to delay spoilage and the development of rancid odors. In poultry, increased feed digestibility from EOs has been linked to improved nutritional absorption. There is a lack of consistent data on the effects of botanicals on digestive processes such as bile and mucus production, saliva secretion, feed digestibility and transit time, and enzyme activity (Bakkali et al. 2008; Fernandez-Panchon et al. 2008; Miguel 2010; Pisoschi and Pop 2015). PUFA aids better nutrient absorption because it increases the surface area available for absorption. The high reactivity of EOs is a further obstacle to their direct application and absorption into food and feed products, and an understanding of their mode of action is also required. Keeping their biological activity stable, regulating their responsiveness, and reducing the impacts of expressing organoleptic characteristics are challenging tasks (Franz et al. 2010; Miguel 2010; Calo et al. 2015). The stability and bioactivity of EOs can be impacted by factors such as production environment temperature, light, metal content, and access to water and oxygen. The temperature of 58°C during feed pelleting, for instance, resulted in a low recovery of the indicator compounds (Maenner et al. 2011). The high reactivity of EOs is a barrier to their direct application and absorption into food and feed products; it is also required to understand their mode of action. Controlled release of EOs is possible thanks to the development of new delivery technologies like encapsulation, which protect EOs' bioactivity and volatile components from oxidation and degradation during feed processing and storage and from the varying conditions in poultry gut (Stevanovi et al. 2018). The antiparasitic effect of EOs in poultry is depicted in Figure 4.

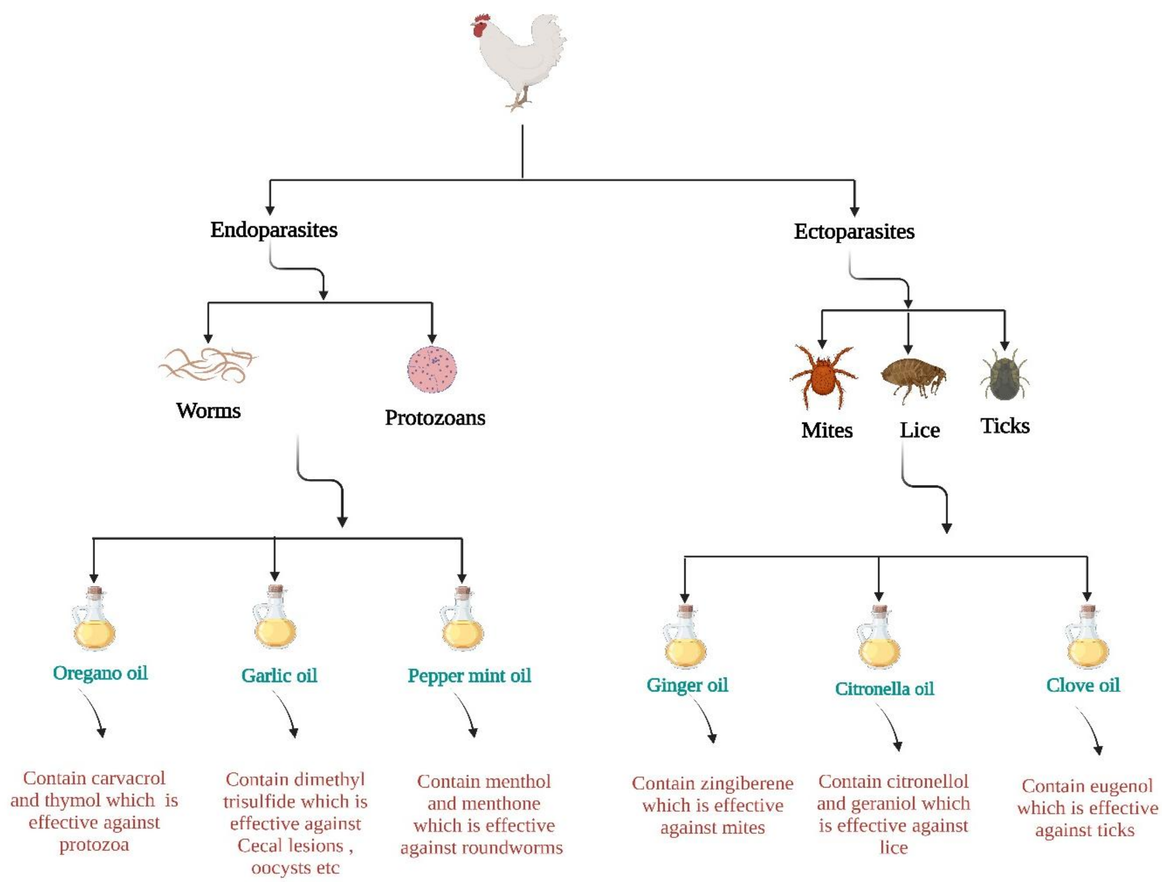

Figure 4 Antiparasitic effect of essential oils in poultry

3.3 Immunomodulatory effect of EOs

EOs are a concoction of various volatile, organic, and aromatic compounds isolated from plants. New studies have shown that the immunomodulatory actions of these drugs are responsible for some of their benefits (Valdivieso et al. 2019). The immune system regulates immunity and disease resistance, and immunomodulator effects specifically alter the immune system. It is essential in poultry because it affects the birds' health, growth, disease resistance, FCR, weight increase, and defense mechanisms. There are many kinds of immunomodulators, such as prebiotics, probiotics, vitamins, adjuvants, polysaccharides, and botanicals (Asif et al. 2020). The primary objective of immunomodulation is to improve the host's ability to resist infection from both external and internal sources. Immunomodulators can be used in place of antibiotics, antimicrobials, and other drugs to achieve the same immune system boosting effects. Furthermore, they enhance immunological and feed molecular qualities, expanding all possible routes for disease avoidance and homeostasis preservation. Since they are not commonly used or added to chicken feed, more work needs to be done to promote their use (Valdivieso-Ugarte et al. 2019; Das et al. 2020). Immunology is a promising new area of study for the prevention and treatment of inflammatory illnesses of the skin, lungs, stomach, central organs, and joints. Immunomodulators regulate the immune system to help patients regain protective immunity during treatment (Patil et al. 2012; Deepak et al. 2020a; Deepak et al. 2020b). Immunomodulation aims to increase the body's natural defenses against invasion by microorganisms and other infectious agents. The primary goals of immunomodulation in poultry are to elicit a strong immune response that lasts for a long time against disease-causing microorganisms; enhance the development of both specific and general immunity during the neonatal period; and reduce susceptibility to disease in poultry (Dhama et al. 2014; Asif et al. 2020). To counteract the immuno-depleting effects of stress and environmental pollution, EOs are beneficial in enhancing local protective immune responses in vulnerable areas of the digestive system, strengthening the immune response after vaccination, and monitoring the body's defenses (Platel and Srinivasan 2004; Das et al. 2020).

Immunostimulants and immunosuppressants are the two most common categories of immunomodulators. Immunosuppressants can be effective in treating autoimmune illnesses and other conditions characterized by an abnormal immune response by dampening the body's natural defenses (Muir et al. 2000; Dhama et al. 2018). Immunostimulants are mediators that help the body's defenses perform better against infection. As an immunotherapeutic treatment, and in immunocompromised individuals, immunostimulants boost immune system baseline levels. Immunostimulant drugs are useful in the treatment of a wide range of medical conditions, including viral infections, cancer, autoimmune illnesses, and immunodeficiency (Hadden 1996; Patil et al. 2012). The Labiatae family, which includes oregano, has received a lot of attention for its potential as a chicken feed ingredient. Broilers' European production efficiency factor improved after being supplemented with 300 ppm of oregano EO (OEO). Based on estimated body weight, viability, FCR, and duration of the trial, it was shown that while 300 ppm OEO in the meal increased secondary total antibody titers, RBCs, and immunoglobulin G (IgG) titer, it did not affect the primary antibody titer. In contrast, another study found that Newcastle disease and avian flu-vaccinated broilers responded positively to 500 and 1000 ppm OEO supplementation, respectively. Treatment of birds with 300 ppm OEO decreased stress markers, namely serum heterophil counts and the heterophil to lymphocyte ratio (H/L ratio) (Huang and Lee 2018).

Chemical feed additives can be replaced with phytochemicals. Broiler dry matter and crude protein digestibility were both greatly improved by the addition of phytochemicals, as were pancreatic and intestinal enzyme secretion (Rice-evans et al. 1995; Jamroz et al. 2006). The immune system's ability to respond and its resistance to outside stressors were both improved by including phytogenic in the diet. Aromatic terpenes and aliphatic terpenoids are two types of phytochemicals made in plants by different mechanisms. This is why phytochemicals suppress inflammatory cytokines and moderate the immune response in chickens (Hadden 1996; Brenes and Roura 2010; Negi 2012). Adding cinnamon to the diet of broilers has been proven to improve growth rates and reduce coliform bacteria in the jejunum and the large intestine. A higher FCR, lymphocyte percentage, and hemoglobin level were seen when either 0.4% or 0.8% cinnamon was introduced to broiler diets. It has been found that cinnamon EO has antioxidant effects (Huang and Lee 2018). Thyme EO is extracted from the thymus plant and contains the active ingredients thymol, carvacrol, p-cymene, and terpinene. Leaf powder and EOs are popular choices as dietary supplements. The EOs raised the amount of Lactobacillus and Bifidobacterium in the ileum and reduced the quantity of *Escherichia coli* while enhancing the cutaneous basophil response to phytohaemagglutinin (Ultee et al. 2002; Plant et al. 2019). In general, a healthier immune system is associated with a lower H/L ratio. Poultry immunity relies heavily on the bacteria in their intestines. Broiler weight gain and FCR were both boosted by thyme. This means that thyme is an effective feed additive for the chicken and egg industries (Brochot et al. 2017; Das et al., 2020). The majority of research looked at this phytogenic, which is found in ground-up turmeric roots (TRP). TRP dramatically boosted blood IgA in 42-day-old broilers exposed to sheep RBCs, while decreasing IgM and IgG levels and increasing the number of monocytes. Broilers subjected to heat stress therapy and supplemented with 0.2% TRP had a lower H/L ratio and a higher total secondary antibody titer against SRBCs. Also, by supplementing their diet with TRP (0.33%) and/or 1.0% (1.16% curcumin), broilers saw sustained increases in FCR. When TRP was administered at dosages of 0.33%, 0.66%, and 1.0%, both abdominal fat and serum triglyceride levels dropped significantly. Therefore, curcumin in the poultry diet may regulate the immune response and boost growth (Huang and Lee 2018).

EOs are a vital aromatic component used as a substitute for antibiotic growth boosters in poultry feed. These are effective against certain infectious microorganisms and parasites. It also promotes the production of digestive enzymes, boosts immunity, and stimulates the appetite (Corbo et al. 2009; Kumar et al. 2022d). Carvacrol, or cymophenol, is a monoterpoid phenol that has a strong, characteristic odor. Carvacrol is found in the EOs of several different plants, including oregano (*Origanum vulgare*), thyme, pepperwort, and wild bergamot (Brochot et al. 2017). The immunomodulatory effects of dietary cinnamaldehyde in broilers were studied by analyzing global gene expression profiles, and the results pointed to antigen presentation, the humoral immune response, and inflammatory illness (Ultee et al. 2000). It was found by *in vitro* testing that cinnamaldehyde treatment of chicken spleen lymphocytes (at doses ranging from 25 to 400 ng/mL) significantly increased cell proliferation compared to the control group. Nitric oxide generation in macrophages was found to increase between 1.2 and 5.0 ng/mL of cinnamonaldehyde, whereas chicken tumor cell growth was inhibited between 0.6 and 2.5 ng/mL and between 10 and 100 ng/mL of cinnamonaldehyde (Brenes and Roura 2010; Sharma et al. 2019). Similarly, adding cinnamon aldehyde to the diet of hens infected with *Eimeria acervulina* or *E. maxima* led to a greater increase in the birds' body weight. The amount of cinnamaldehyde employed in this research was, admittedly, quite small. Animal studies have demonstrated that thymol, the primary component of both thyme and oregano EOs, has anti-inflammatory properties similar to those of the carvacrol isomer. Thymol also inhibits dendritic cell maturation and promotes T cell proliferation *in vitro*. The transcription factor NF-κB was drastically reduced in the jejunum of broilers that were supplemented with thyme powder, which contains the EOs such as thymol (50.48%), terpinene (11.03%), p-cymene (9.77%), and carvacrol (4.3%). The levels of pro-inflammatory cytokines were also reduced in broilers given thyme powder. This is consistent with previous research and lends credence to the idea that thyme's anti-inflammatory capabilities justify its usage in this context (Calo et al. 2015; Huang and Lee 2018).

3.4 Antimicrobial effect of EOs

The development of antibiotics, which had its heyday in the 1950s and 1970s, was made possible by the realization that germs cause a range of ailments in the late 19th century. Despite this, no new antibiotic classes had been discovered (Calo et al. 2015). On the other hand, improper antibiotic use led to the evolution of germs that are resistant to treatment. One of the options is to employ antibiotics as antimicrobial growth promoters for poultry; therefore, it is crucial to create suitable alternatives for antibiotics to preserve the efficiency of the poultry sector as it is currently run, and one promising method is the use of EOs. Most people believe that EOs are safer and more effective than antibiotics since they are all-natural and chemical-free (Dhama et al. 2018; Zhai et al. 2018; Wińska et al. 2019; Ebani and Mancianti, 2020). One of the main factors that may affect the yield of laying chickens is the antibacterial activity of EO. For example, cinnamaldehyde, an EO extracted from the cinnamon plant, inhibits the growth of pathogenic microorganisms. It has been documented that cinnamaldehyde strongly inhibits the growth of *Clostridium perfringens* and *Bacteroides fragilis*. EOs have been shown to fight dangerous microorganisms, although how this happens is not well understood (Brochot et al. 2017; Asif et al. 2020; Chandran 2021a). The effectiveness appears to depend on a variety of factors, including the pH, chemical make-up of the active substances, population, and kind of impacted intestinal bacteria. Coumarin and alkaloids, as well as terpenoids, phenolics, metal chelation by phenol, and flavonoids, all have antimicrobial inhibitory effects that may cause cell membrane damage (Widodo 2020).

Antimicrobial properties of EOs have been studied in vitro multiple times, and carvacrol and thymol have been found most efficient against pathogenic enteric bacteria like *E. coli* and *Salmonella typhimurium* (Tassou et al. 1995; Dhama et al. 2014). Hydrophilic components of the outer membrane may account for the similarities between EOs and gram-positive bacteria. Alterations in the immune response influenced the levels of pathogens (Negi 2012). Antibody titers against infectious bursal disease and Newcastle disease in layer chickens rose when EOs was introduced into their diet. When properly prepared, ginger has antibacterial properties (Dorman and Deans 2000; Asif et al. 2020). It is also possible that ginger-containing feed additions benefited the antioxidant and immune systems of broilers. Given the presence of microbial toxins, this may be due to ginger's powerful antioxidant effects. Several substitutes have been employed as antibacterial agents in poultry production (Brochot et al. 2017). Using ginger extract as a feed supplement would increase the production of low-cholesterol eggs, which are preferred by consumers and clients because cholesterol is a marker for cardiovascular diseases. Studies on poultry have consistently shown that the effects of ginger and its derivatives are on par with antibiotics. Not only are the correct dosage and method of administration essential when utilizing these antibiotic alternatives, but so is the correct use of the antibiotics themselves (Calo et al.

2015). When administered together, many EOs have enhanced antibacterial action. The bactericidal MICs for eugenol, thymol, and carvacrol against *Listeria innocua* were 150, 250, and 450 mg/kg, respectively. A mixture of 62.5 mg/kg thymol and 75 mg/kg carvacrol completely suppressed the growth of *Listeria innocua*, as did a mixture of 75 mg/kg carvacrol, 31.25 mg/kg thymol, and 56.25 mg/kg eugenol. To lessen the financial and experiential costs of using antimicrobial preservatives, combining EOs may be an option (Cannas et al. 2016). Numerous studies have shown that EOs can inhibit the growth of bacteria and other microorganisms, but the mechanisms underlying this effect remain unknown. Several hypotheses have been proposed to explain the mechanisms of action of the chemical components of EOs. Because of the complexity of their composition, the antibacterial effects of EOs cannot be isolated to the action of a single element. Many studies have linked the antibacterial activity of EOs to the lipophilic properties that allow them to penetrate bacterial membranes and exert inhibitory activity on the cell's functional capabilities once inside (Calo et al. 2015; Valdivieso-Ugarte et al. 2019). Components present in certain EOs that have been shown to have antimicrobial effects are depicted in Table 3.

3.5 Anticoccidial effect of EOs

Coccidiosis is a common parasitosis in chickens caused by protozoa of the genus Eimeria, and it manifests itself through malnutrition and decreased performance. The incubation time of coccidiosis varies from four to six days, depending on the number of hosts present and other risk factors such as contact with faeces. Parasites cause malabsorption, diarrhoea, and poor weight gain by establishing a colony in the intestinal cells of the host and triggering the host's immune system to attack these parasites (Cannas et al. 2016). Vaccines against coccidiosis are effective in several studies. Live vaccines are the most common and convenient method of improving host immunity, and they are effective against infectious species of Eimeria. However, due to the lengthy period during which broilers are raised, live vaccines

Table 3. Select essential oil components with demonstrated antimicrobial activity

Plant	Components in EOs	Composition percent	References
Coriandrum sativum	Linalool E-z-decanal	26% 20%	Delaquis et al. (2002); Mahfuz et al. (2021)
Coriandrum sativum	Linalool E-z-decanal	70%	Delaquis et al. (2002); Mahfuz et al. (2021)
Cinnamomum zelandicum	Trans cinnamaldehyde	65%	Lis-Balchin et al. (1999); Zhai et al. (2018); Mahfuz et al. (2021)
Origanum vulgare	Terpinene p-cymene	52-64% 2-5%	Demetzos et al. (2001); Marino et al. (2001)
Rosemarinus officinalis	α-pinene Bornyl acetate Camphor 1-8 cineole	2-25% 0-17% 2-14% 3-89%	Daferera et al. (2003); Zhai et al. (2018); Abd El-Hack et al. (2022)
Thymus vulgaris	Thymol Carvacrol γ-terpene	10-64% 2-11% 2-31%	Juliano et al. (2000); Mahfuz et al. (2021)
Salvia officinalis L	Camphor α-pinene β-pinene 1-8-cineole α-thujone	6-15% 4-5% 2-10% 6-14% 20-42%	Marino et al. (2001); Abd El-Hack et al. (2022)
Syzgiuma romanticum	Eugenyl acetate Eugenol	75-85% 8-15%	Bauer et al. (2008); Zhai et al. (2018)
Bubonium imbricatum and *Cladanthus arabicus*	Oxygenated monoterpenes cis-chrysanthenyl acetate Thymol Isobutyrate Monoterpenes hydrocarbon Sabinene Beta-pinene Alpha-pinene	61.4% 31.4% 3.4% 75.8% 31.1% 16.7% 12.3% 5.3%	Aghraz et al. (2018); Hoffmann (2020)

might produce reactions that can negatively affect flock performance in the event of inadequate management. This shortcoming led to the development of attenuated immunizations with reduced pathogenicity, but their production is expensive (Valdivieso-Ugarte et al. 2019). EOs and their constituents have been studied extensively for their potential to reduce the prevalence of avian coccidiosis. Botanical compounds, especially EOs, added to feed can serve as excellent replacements for anticoccidial drugs, lowering or eliminating the requirement for medication in the treatment and control of avian coccidiosis (Idris et al. 2017). Chicks that were treated with EOs had much lower rates of intestinal lesions and coccidian oocyst discharge (Zhai et al. 2018).

EOs have direct anticoccidial actions, including modifying the ultrastructure of mitochondrial membranes, halting the formation of glycoproteins, and blocking the activity of the cysteine protease cruzain enzyme. EOs help the host by protecting against free radicals and immunomodulating the immune system by scavenging reactive oxygen species (ROS) produced during parasite invasion (Valdivieso-Ugarte et al. 2019; Prakash et al. 2021a). EOs are potent botanical substances that block and destroy parasitic invasion by either directly disrupting parasite metabolism or indirectly doing so by bolstering the antioxidant defenses and immune response of the host. EOs are potent botanical agents that can successfully limit and eradicate parasitic invasion by interfering with parasite metabolism in two ways: directly and indirectly (Idris et al. 2017; Hoffmann 2020).

Poultry that had been artificially infected with *Eimerella tenella* had a lower oocyst mass per gram of excreta when oregano EOs (300 mg/kg) were administered. An indicator of the severity of avian coccidial infection was the number of *Eimeria* oocysts found in bird poop (Cannas et al. 2016). Extensive studies on the anticoccidial effects of oregano oil showed that it was effective against *Eimeria tenella*, *E. maxima*, and *E. acervulina*. It has been claimed that using EOs and coccidial vaccinations together is an effective alternative for avoiding avian coccidiosis. Coccidia-infected birds continue to grow more slowly than healthy birds, even when both groups consume the same diet. Oregano EO's major components are carvacrol and thymol, which have anticoccidial activity against infections caused by *E. tenella* and a mixture of *Eimeria* spp (Krishan and Narang 2014). Beneficial effects against intestinal parasites, especially Eimeria species, have been demonstrated for extracts and EOs from the plant's *Origanum vulgare*, *Allium cepa*, *Echinacea purpurea*, *Chenopodium ambrosioides*, *Mentha* spp., and *Allium sativum*. Many studies have shown that *Origanum vulgare* EOs have anticoccidial action (Idris et al., 2017). Eimeria oocyst release in avian faeces is often considered the major sign for predicting coccidial infection. Treatment of infected birds with EOs and bioactive plant extracts from certain herbs reduces the damage caused by the discharge of coccidial faecal oocysts on the intestinal epithelium. Researchers found that fewer coccidial oocysts were found in the litter when broiler chicks were given oregano EO and were also vaccinated (Bozkurt et al. 2013; Prakash et al. 2021b)

3.6 Antioxidant effect of EOs

Antioxidants are used as food additives to protect perishables from oxidative damage produced by free radicals. Spices have been utilized for thousands of years, and their antioxidant qualities have been well-known for centuries. Industrial processing makes use of synthetic antioxidants to lengthen the storage life of foods. Toxicologists have expressed concern about the possible carcinogenic properties of two synthetic antioxidants, butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA). There has been a growing backlash against chemical additives in food. This has sparked a surge in interest in discovering whether or not certain natural additives can function as antioxidants (Amorati et al. 2013; Dhama et al. 2014; Dhama et al. 2018). Antioxidant activity in three different commercial cinnamon extracts was found to be comparable to that of the synthetic antioxidant BHT. Researchers used rosemary, olive leaf extract, and several types of tea to show off the antioxidant powers of their respective ingredients (Brenes and Roura 2010; Valdivieso-Ugarte et al. 2019). Vitamins are a type of nutrient that, to aid in a wide variety of metabolic processes and the efficient utilization of other nutrients, must be ingested daily, albeit in extremely minute quantities. The constituents of animal meals contain them naturally, although supplementation is still required especially antioxidants found outside the body, such as vitamins E and C. According to research conducted on chickens, they have a significant role in the bird's ability to cope with oxidative stress. Vitamin E, to provide just one example, is crucial in maintaining the integrity of cell membranes. Broilers and ducks fed with different EOs (0.2% of the diet) gained and matured at similar rates. Also, a vitamin E supplement of tomato pomace (30%) added to the chickens' diet for 21 days did not influence their weight gain. A synthetic antioxidant containing vitamin C is offered to poultry, even though there is not much research on vitamin C (Cavani et al. 2009; Righi et al. 2021). Antioxidant properties of plant-derived EO components are represented in Table 4.

3.7 Antiparasitic effect of EOs

EOs have shown promise as prophylactic treatments against several arthropod ectoparasites, including lice, mites, and ticks, and this area of study continues to expand. The presence of the latter ingredient provides evidence that their mode of action involves

Table 4 Antioxidant constituents in essential oils derived from plants

EOs extracted from plants	Components of EOs	Procedure used	Antioxidant effect	References
Bay leaf, black pepper, coriander, cumin, garlic, ginger, mustard, onion, and turmeric	Coriander and cumin seed oil, linalool, p-coumaric acid	DPPH method	Cumin 163.50 (µg/mL), coriander 150.62 (µg/mL), mustard 155.16 (µg/mL)	Bag and Chattopadhyay (2015)
Deracocephalum moldávica and *Melissa officinalis* and	Citronellal, citral and thymol (in *M. officinalis*); geranial, geranyl acetate geraniol, and neral (in *D. moldavica*)	DPPH method	Both EOs had a stronger action than ascorbic acid in the preservation of β-carotene molecules.	Bag and Chattopadhyay (2015); Sharifi-Rad et al. (2021)
Lovage, basil, parsley, and thyme	β-phellandrene, γ-terpinene, β-myrcene, and α-pinene were the major compounds	DPPH method	*Bacillis cereus* MIC (minimum inhibitory concentration) values: Basil - 10.8 µL/mL Thyme - 0.56 µL/mL *Staphylococcus aureus* MIC values: Basil - 2.45 µL/mL Thyme - 0.06 µL/mL. *Psuedomonas aeruginosa* MIC values: Basil - 10.80 µL/mL Thyme - 0.27 µL/mL Salmonella Typhimurium MIC values: Basil - 22.68 µL/mL Thyme - 0.56 µL/mL	Semeniuc et al. (2018)
Ruta chalepensis	β-linalool, 2-undecanone, linalyl acetate, and 2-nonanone were the major compounds	DPPH method	Percentages of inhibition for *R. chalepensis* collected from Jerusalem and hebron were 6.9 ± 0.94 µg/mL (69.56%) and 7.8 ± 1.05 µg/mL (61.53%)	Jaradat et al. (2017)
Achillea millefolium L., *Anethum graveolens L.*, and *Carum copticum*	*A. millefolium*: thymol, carvacrol, borneol, and limonene; *A. graveolens*: thymol, limonene, α-pinene; and C. copticum: thymol, sabinene, and borneol	DPPH, FRAP and BCBT assays	In all tests performed, *A. millefolium* showed the highest antioxidant activity	Kazemi (2015)
Cupressus macrocarpa and *Corymbia citriodora*	Terpinen-4-ol (23.7%), α-phellandrene (19.2%), α-citronellol (17.3%), and citronellal were the major constituents of *C. macrocarpa*, and α-citronellal (56%), α-citronellol (14.7%), citronellol acetate (12.3%), isopulegol, and eucalyptol were the primary constituents of *C. citriodora*	Standard butylhydro xytoluene	The concentration of *C. citriodora* was greater than that of the reference compound butylhydroxytoluene but less than that of the positive control	Salem et al. (2018)
Fagopyrum esculentum, *Fagopyrum tataricum*, and *Fagopyrum Cymosum*	*F. esculentum*: Nonanoic acid (7.58%), (E)-3-hexen-1-ol (6.52%), benzothiazole (5.08%), 2-pentadecanone (18.61%), and eugenol (17.18%); *F. tataricum*: 1,2-benzenedicarboxylic acid, bis(2-methylpropyl) ester (13.19%) and (E,E)-farnesylacetone (7.15%); *F. cymosum*: Eugenol (12.22%), (E)-3-hexen-1-yl acetate (8.03%), linalool oxide (7.47%), 1-hexanol (7.07%), and benzothiazole (6.72%)	DPPH and BCBT assays	The antioxidant potential of three EOs is comparable in both tested procedures	Zhao et al. (2018)

EOs extracted from plants	Components of EOs	Procedure used	Antioxidant effect	References
Mentha spicata	Limonene, 1,8-cineole, and carvone were the major compounds	DPPH method, reducing power, chelating power, and BCBT assays	DPPH IC50 3.08 ± 0.07, reducing power EC50, 2.49 ± 0.07, chelating power IC50, 6.33 ± 0.12, and BCBT 6.4 ± 0.07	Snoussi et al. (2016)

a neurotoxic rather than just a mechanical pathway. Immersion, skin contact with treated surfaces, and inhalation of the vapors produced by these oils have all been demonstrated to be toxic. However, because EOs are so volatile, there is a common misconception that their effects wear off quickly. It is not known whether the purported superiority of EOs over standard ectoparasite treatments is attributable to neurotoxicity or mechanical asphyxiation (Ellse and Wall 2013). Several plants and their EOs have been studied for their potential antiparasitic effects. Mint (Mentha spp.), onion (*Allium cepa*), garlic (*A. sativum*) EOs, and seeds, for example, have been reported to be effective against gastrointestinal parasitism. Coccidia-infected birds grow more slowly than healthy birds, even after being fed the same diet. Anticoccidial activity of thymol and carvacrol, the main components of oregano EO, has been demonstrated against both mixed *Eimeria* spp. infection and *E. tenella* infection. Further *in vivo* and *in vitro* tests demonstrated that phenols, in particular, can be used as oocysticides to kill *Eimeria tenella* (Krishan and Narang 2014; Kumari et al. 2022b; Kumar et al. 2022c).

Lice, mites, and ticks are just some of the many ectoparasites that are particularly vulnerable to several EOs. Many different methods of exposure, such as submersion and skin contact with EO-treated surfaces, have demonstrated EO's effectiveness. It was observed that even low concentrations of them in spray form were highly effective (Chandran 2021a; Kumari et al. 2022a). The oils' neurotoxic and suffocative effects on parasites account for their insecticidal effects. Tea tree oil contains a monoterpenoid called terpinen-4-ol, and it blocks the acetylcholinesterase enzyme, which is essential for the transmission of action potentials in arthropods. In addition to their neurotoxic effect, oils' hydrophobic properties may have mechanical impacts on the parasite, which may disrupt the cuticular waxes and clog their spiracles, killing the parasites (Raza et al. 2022; Kumar et al. 2022c). Poultry ectoparasites are big business, especially *Ornithonyssus bursa* (a mite) and *Menopon gallinae* (chicken lice). Layers may not die from them directly, but they do suffer annoyance, weakness, and reduced egg production. In particular, the EOs found in ginger and citronella (lemon grass) are more efficient at lessening the prevalence of these parasites. Chemical constituents and active components of terpenes and oleoresin in ginger and citronella are mostly responsible for this outcome (Vigad et al. 2021). Several plant-based EOs have been used to treat *Dermanyssus gallinae*, and these EOs have proven to be successful. Commonly used EOs against chicken red mites include those derived from the plants such as clove (*E. caryophyllata*), coriander (*C. sativum*), and cade (*Juniperus oxycedrus*) (Abbas et al. 2018; Vigad et al. 2021).

3.8 Anti-inflammatory effect of EOs

Inflammation is a natural protective reaction triggered by tissue injury or damaged or dead host cells to fight off and eliminate foreign invaders (Mohammadi and Kim 2018). It has been proven that phenolic compounds found in a variety of aromatic plants can help strengthen the immune system. The anti-inflammatory characteristics of phenolic compounds have garnered a lot of attention because of their potential to reduce inflammation by blocking the production of pro-inflammatory prostaglandins and nitric oxide. The phenolic components of EOs are employed as feed additives because of their anti-inflammatory properties. Immune function is altered by phenolic compounds in several ways, including increased phagocytosis, secretion of cytokines, and interferon, and increased production of immunoglobulins (Greathead 2003; Hoffmann 2020; Mahfuz et al. 2021). EOs contain terpenoids and flavonoids, two chemicals with anti-inflammatory properties that block prostaglandin absorption. Another molecule presents in EOs that has been shown to alleviate pain, reduce swelling, and reduce inflammation is 1,8-cineole, which is found in eucalyptus oil, and linalool, which is found in lavender oil. Other plants having anti-inflammatory qualities include marigolds, anise, chamomile, and licorice (Wilkinson et al. 2003; Franz et al. 2010). Turmeric, also known as *Curcuma longa*, goes by several other names. The rhizome of this plant is an important source of curcuminoids, curlone, and zingiberene like active components. Anti-inflammatory, anti-cancer, and anti-hepatotoxic characteristics are the principal impacts of this herb on oxidation (Dosoky and Setzer 2018; Raza et al. 2022).

Other alkaloids, such as isoquinoline and acetylsalicylic acid, have been shown to have an anti-inflammatory impact by lowering the production of inflammatory cytokines. These phenolic compound-rich alkaloids can affect gut health by modulating the inflammatory cascade and blocking NF-κB activation. The cellular and humoral immune response was enhanced in broilers that were given thymol and carvacrol EOs (Greathead 2003; Hoffmann 2020). Plant flavonoids genistein (5 mg/kg) and hesperidin (20 mg/kg) were administered to broilers that had been exposed to lipopolysaccharide (LPS), and the animals showed enhanced immune activation and an improvement in gut architecture. Reduced production of IFN-γ, IL-4, IL-13, and IL-18 in LPSchallenged broilers fed phenolic-rich diets is evidence that plant polyphenols have immunomodulatory effects. Broilers' cell-mediated and humoral immune responses could benefit from a diet of 150 mg/kg of saponins, a phenolic substance derived from soapnut (*Sapindus mukorossi*) (Mahfuz et al. 2021). Proof of carvacrol's anti-inflammatory effects in lipopolysaccharide-challenged broilers was found when the phenolic component carvacrol EOs was fed to the animals (Liu et al. 2019).

The increased monocyte counts in laying hens treated with fennel EO at 300 mg/kg and the enhanced lymphocyte counts in hens treated with thyme powder at 0.2% are both signs of good health. The increased production lifespan and thorough immunization regimens of the laying chickens from day old to curved age may inadvertently improve immune function thanks to dietary phenolic substances. Antibody response to the ND vaccine was enhanced in laying hens fed a combination of 200 mg/kg of EOs from *Mentha piperita*, *Thymus vulgaris*, *Anethum graveolens*, and *Rosmarinus officinalis* (Mahfuz et al. 2021). Non-volatile secondary metabolites like rosmarinic acid, oleanolic acid, and ursolic acid have been identified as the primary anti-inflammatory agents in EOs from the *Origanum* species (Shen et al. 2010). EOs can be used to counteract the effects of free radical scavengers. They can serve as anti-inflammatory drugs because an oxidative burst is a sign of inflammation. The anti-inflammatory effects of several EOs have been the subject of scientific study. For example, chamomile EO has been used for generations to alleviate the discomfort of eczema, dermatitis, and other skin irritations by acting as an anti-inflammatory. Anti-inflammatory preparations have also made use of a wide variety of other plants (pine, clove, and myrrh) and EOs (eucalyptus, rosemary, lavender, and millefolia) (Mohammadi and Kim 2018).

3.9 Effect of EOs on digestive and respiratory systems

Studies have shown that EOs from spices and herbs can aid digestion, hence these ingredients are commonly utilized in cooking. They stimulate the production of digestive enzymes such as trypsin and amylase (Jang et al. 2007). Capsaicin, curcumin, and piperine are just a few of the pungent principles found in EOs that have been shown to increase digestive enzyme activity in the intestinal mucosa and pancreas (Gopi et al. 2014). Researchers found that the spices or their constituents triggered the secretion of bile salts. EOs, alone or in combination, can be used to stimulate growth in broiler chickens. The body weight of broilers increased more when they were fed a diet containing peppermint. EOs improves chicken growth performance by increasing the production of digestive enzymes and balancing the microbes in the chicken's digestive tract. Feed consumption in broilers was drastically cut back when they were given a mixture of herbal EOs. This study provides strong evidence that supplementing with an EO mixture during the stage of development increases productivity, possibly by altering gut architecture and increasing digestive enzyme levels in broiler chicken (Botsoglou et al. 2002; Botsoglou et al. 2005; Yang et al. 2018). For this reason, EO may eventually replace the antibiotic growth promoter in the commercial chicken business. Antibacterial, antioxidant, and antiseptic activities have all been attributed to thymol and carvacrol, two components of thyme and oregano, respectively (Lee and Ahn 1998; Yang et al. 2018). Supplementing with EO improves intestinal microbiota and digestive enzymes, which may contribute to improved growth performance, but the mechanisms by which this occurs are still unknown (Helander et al. 1998). At 50mg/kg, the EO blend significantly increased both the total and specific pancreatic activities of trypsin. Proximal maltase activity was significantly higher in birds given 50ppm of EO compared to those fed a basal diet or a diet containing antibiotics and 25ppm of EO (Jang et al. 2007).

EOs optimizes the microbiome in the intestines, prompt the production of digestive enzymes, and boost the health and productivity of chickens. Broilers that were given a blend of herbal EOs showed a marked decrease in their need for food. The effects of EO components on broiler chicks' growth performance and digestive enzymes have not been the subject of many randomized controlled trials. Regardless, studies demonstrate that a particular EO combination can stimulate the body's natural production of digestive enzymes in hens (William 2001; Botsoglou et al. 2002; Botsoglou et al. 2005). The research was conducted to determine how different EO meal components affected the growth performance, digestive enzyme activity, and macronutrient digestibility of female broiler chickens. There is evidence that dietary EOs decrease blood cholesterol in hens, thus we also measured the plasma lipid level and the fatty acid composition of adipose tissue (Yu et al. 1994). Virus infections are among the most serious challenges facing the chicken business today. Mycotoxin exposure, viral illnesses characterized by immunosuppressive symptoms, ineffective vaccinations, and the inappropriate use of various antibiotics and drug growth boosters are only a few of the causes (Galal et al. 2016). Experimental testing of the commercial EO product AROMAX® demonstrated that indications of respiratory illness were reduced and humoral and local immune responses were improved in broilers with respiratory diseases and respiratory issues due to insufficient treatment.

3.10 Other beneficial effects (egg and meat quality/ biochemical/ hematological) of EOs

Witkowska and Sowinska (2013) conducted an inspiring investigation that demonstrated the efficacy of air sanitizers using either thyme or peppermint oil alone in enhancing hygienic conditions in a chicken house. Seven different doses (0.025, 0.050, 0.0100, 0.0200, 0.0600, and 0.625g/kg) of a plant feed additive containing a mixture of EOs from black cumin, thyme, rosemary, fennel, and anise were tested on the growth performance, eggshell quality, biomechanical characteristics, and bone mineralization of egg-laying fowls. Findings suggest that laying hens benefit from dietary EOs at low to medium concentrations, but that these values are negatively impacted at higher concentrations (Olgun 2016; Cuppett and Hall 1998).

Significant increases in egg production, feed efficiency, and a decrease in cracked egg percentage were all seen after the EO mixture was added to the diet at a dose of 24mg/kg (Cabuk et al. 2006). A recent randomized controlled trial looked at how changing the chickens' habitat and supplementing them with essential oils (rosemary and cinnamon) affected egg production and quality. The hens were housed in cages and on floors while the effects of three different oils on blood biochemistry, hematological parameters, egg quality, immunological status, oxidative level, and layer production were examined. Egg production and performance were not significantly different between housing types; however the former had a positive effect on both. Results showed that treated groups (with EOs) had significantly higher and better blood cholesterol, aspartate aminotransferase (AST), alanine aminotransferase (ALT), immunity, antioxidant, feed conversion, calcium, phosphorus, feed intake, and urea levels compared to control groups (Botsoglou et al. 2002; Botsoglou et al. 2005; Abo Ghanima et al. 2020; Hoffmann 2020). Lavender oil at doses of 300 and 600mg/kg was included in the feed throughout a 42-day experiment. Improvements in gut flora, development rate, and intestinal mucosa were observed at a dose of 600 mg/kg lavender EO. The antioxidant status of the serum and the liver improved (Greathead 2003; Hoffmann 2020).

Lavender EO in the diet is a superior substitute for AGPs for production growth (Barbarestani et al. 2020). A new study suggests that the orange EOs could be used as a chicken meat preservative. The oxidation of lipids in meat (chicken) is decreased by this procedure without any noticeable changes to the meat's color, flavor, pH, or quality (Bozkurt et al. 2014a). The use of thyme and its EOs in feed was the subject of an experiment. The effects of 5, 10, and 15 mg/kg of thyme and 0.5, 1.0, and 1.5g/kg of its EOs on growth performance, antioxidant status, blood picture, and immunological response in broiler chickens were evaluated. Numerous chicken metrics benefited greatly from this investigation (Rice-evans et al. 1995; Ismail et al. 2019).

Broilers that were given feed containing EOs such as *Lippie rotundifolia* and lemon grass were subjected to an experiment in which their histopathological lesions, hematological, and liver function were evaluated. There was a statistically significant difference between the MCV and MCH of the negative control group and the treatment group (broilers). Histopathology scores were greater in broilers given *L. rotundifolia* oil supplements, but these changes were seen in all groups (Santos et al. 2019). EOs of lemon grass and *L. rotundifolia* are sometimes used as a substitute for increasing performance because of their antimicrobial qualities (Souza et al. 2015; Assis et al. 2017; Azevedo et al. 2017). The goal of this study was to determine if broiler chicks benefited from being fed varied amounts of anise, powdered curcuma seeds, and fenugreek. The estimations also included feed efficiency, productive performance, carcass characteristics, and a handful of blood components. The data showed that the FCR, live body weight and overall gain all saw significant improvements. There was no change in feed consumption despite the nutritional enhancement of these oils (Amein et al. 2019). By enhancing the activity of enzymes like protease, lipase, and amylase, curcumin improved digestion and metabolism when given to animal feed (Platel and Srinivasan 2000). In addition to lowering blood glucose, triglyceride, and LDL cholesterol levels, curcumin improves liver function (Gandhi et al. 2011).

The growth, carcass quality, and blood profile of birds were found to be enhanced when the ginger powder was administered as a natural supplement in a study (day-old broilers). In this study, we employed doses of 0%, 0.25%, 0.40%, and 0.60%. According to the findings of this study, there was no statistically significant difference in the amount of weight that the various groups of birds gained. The feed conversion rate, however, was higher than that of the control group. There were no noticeable changes between the groups in terms of biochemical values or hematological values. Therefore, it was concluded that the amount of ginger employed in this study's experimental trial was not enough to stimulate the growth of chicks (Hassan et al. 2019). Soybean oil is commonly used in broiler diets, but for this experiment, linseed oil (high in omega 3) and pomegranate peel extract were substituted. The lipid profile, fatty acid contents, avian performance, flavonoids, and phenols were just some of the many factors evaluated. By changing the diet to include pomegranate peel extract and linseed oil, it was able to lower the amount of fat in poultry meat. Linseed oil was also found to reduce the total cholesterol and triglycerides fatty acid levels in the serum of broiler chickens. Protein, fat, and carbohydrate enrichment in the diet increased phenol and flavonoid content in chicken (Kishawy et al. 2019). In a separate investigation on the properties of Oregano EO, the oil was included in the diet of commercial laying hens. The researchers wanted to see if any shifts in metabolic profile would indicate a problem with liver function or lipid/protein metabolism. Oregano essential oil doses of 0mg/kg of feed, 50mg/kg of feed, 100mg/kg of feed, 150mg/kg of feed, and 200mg groups given doses of 150

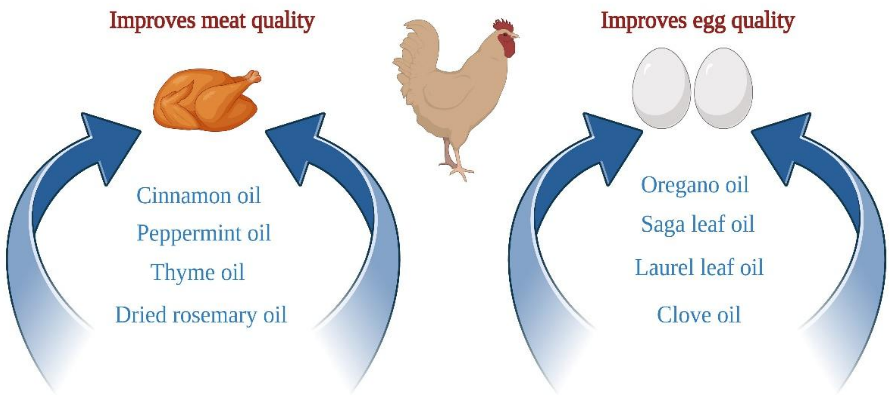

Figure 5 Various essential have potential impact on enhancing the meat quality and egg quality in the poultry industry

and 200mg/kg showed elevated levels of globulins and proteins (Migliorini et al. 2019). Additionally, broiler hens exposed to a high concentration of EO from the herb oregano had elevated levels of cholesterol in their blood serum (Basmacioglu Malayoglu et al. 2010). Various EOs that have beneficial effects on enhancing egg and meat quality in poultry is represented in Figure 5.

4 Side effects of usage of EOs

Although EOs serve several purposes, they are also to blame for the host's toxicity and unwanted side effects. Volatile oils relax the membranes of organelles and the cytoplasm, including the peroxisome and mitochondria. The mitochondrial membrane is disrupted by EOS, affecting the cell's capacity to depolarize via alterations in ion channels and hence ATP generation (Hoffmann 2020). The hydrophobic and lipophilic characteristics of EOs like thymol and carvacrol make them toxic to the intestinal cells and the mucosa layer that lines them. EOs derived from Egyptian and Chinese plants have also been related to the development of fumigant toxicity. It is important to remember that essential/volatile oils and the metabolites they produce can cause hypersensitivity reactions and symptoms in certain people (Jamroz et al. 2006; Raza et al. 2022).

However, while several EOs have been found to have beneficial anti-oxidant qualities, their use in meat and meat products is not without its downsides. To begin, some EOs' interactions with food's specific components and structural makeup can reduce the food's nutritional value (Lambert et al. 2001; Fernandez-Panchon et al. 2008; Migliorini et al. 2019; Sharifi-Rad et al. 2021). When applied to meat and meat products, the effects of EOs may be greatly attenuated by the presence of lipids, carbohydrates, proteins, and salts in food systems, as opposed to what is observed in vitro. Ham brushed with canola oil has the same amount of fat as pate. Herbal EOs like mint and cilantro are largely ineffective (Basmacioglu Malayoglu et al. 2010; Dhama et al. 2014; Dhama et al. 2018). When compared to synthetic antioxidants, the antioxidant power of most EOs is lesser and their price is higher. There may be inconsistency in EO quality and composition because of potential influences from harvest season and plant species. Further, their application as food preservatives has been limited because of the need for their presence in extremely high concentrations to exert sufficient activity (Juliano et al. 2000; Giovannini et al. 2016). The aroma and flavor of food can be ruined by the use of some EOs. The potent scents of these EOs, even at low absorption rates, may have been a major factor in turning off potential buyers. So, they are best reserved for usage with fiery dishes that feature strong seasonings or herbs (Jayasena and Jo 2014; Leherbauer and Stappen 2020).

5 Conclusions and future prospects

New research into the creation of safe and effective growth enhancers has been motivated by growing pressure on the chicken industry to limit or eliminate the use of antibiotics in feed as growth enhancers. Some of the most cutting-edge innovations in the feed additives industry include extracts of herbs and essential oils. Herbs, spices, and bioactive compounds have been used therapeutically for thousands of years, and their benefits to human health have been documented in a wide range of culinary traditions and scientific studies. Some bioactive chemicals found in a variety of plants could serve as useful additives to poultry feed. Extracts from common herbs and spices are said to affect the chicken's performance, oronasal somatosensing, digestion, lipid metabolism, prevention of tissue oxidation, and control of microbial populations. As a result, EOs probably affect not just the microbiota but also peripheral chemosensing and animal metabolism. It may be helpful to have a better grasp of the mechanism of action and effects of individual compounds before attempting to formulate mixtures of chemicals to boost efficacy.

More research into the specific class of EOs is required to better understand their practical applications for the poultry sciences. This includes looking at dose-responses, effects in combination with different commercial feed formulations, and the impact of chicken genetics and raising circumstances. Since these extracts are likely to be employed as natural additives in the food and feed industries, it is important to provide analytical methods for tracking the presence of active components in foods and animal feeds. Unfortunately, there is not yet a reliable analytical method for detecting and measuring EO residues in animal feed and other food sources. These testing procedures are necessary for achieving feed traceability and decreasing residual levels in carcasses, eggs, and milk. The problem of the instability of particular EO compounds in feed processing requires additional attention. A method for identifying and standardizing the functional components. Since the inclusion of a single herb or its extracted EO in meals may not always have the same effect on broiler performance, it is crucial to analyze the chemical quality of a plant extract to discover optimal compositions of secondary plant compounds for future reference. More study is required to determine if and how EOs react with the chemicals and additives used in feed. The intricacy of the number and diversity of bioactive compounds and their interactions slows the rate of progress in the study of raw plant materials and plant extract preparations. Taking use of the synergistic effects amongst EOs may boost their antibacterial activity while decreasing the concentrations required to obtain the same result. Interactions with other feed additives, such as organic acids and probiotics, should also be explored.

In vitro studies have shown that EOs and their constituents have potent antibacterial, antioxidant, immunomodulatory, and anti-inflammatory effects. It is widely agreed that these chemicals are safe to use as feed additives. Only in cases where resistance to or unpleasant side effects from already available approved medications or chemical substances, like antioxidants or antimicrobials, might the EOs and their derivative compounds are considered. Since there is such a wide variety of EOs, it may be necessary for researchers to zero in on certain compounds, including carvacrol, thymol, eugenol, alicin, and cinnamaldehyde, to see whether or not they can serve as substitutes for antibiotic growth promoters in poultry diets. These chemicals and their mixtures need more research on their chemical and biological properties and activities. We can conclude that EOs and related constituents can be employed as natural, non-antibiotic growth boosters in poultry diets from the available in vivo data. However, there is a dearth of credible information showing how this improves poultry's ability to digest nutrients. Applications of EOs in poultry can be successful in a variety of ways. The main factors to think about are the variations in feed inclusion levels and active components, animal genetics, and overall diet composition. An obvious prerequisite for the design of highly effective EOs-based products is the improvement of knowledge and understanding of the complex ecosystem of the gastrointestinal tract of diverse animals. In general, EOs are beneficial, but our understanding of how they might be used in animal nutrition is still sketchy, thus additional study is needed to determine its precise mode of action, as well as the optimal supplementation dosage and duration.

EOs are used for *in vitro* as well as *in vivo* testing on chickens. EOs have been shown to increase the productivity of broiler chickens by reducing their feed consumption, causing them to gain weight more quickly, and boosting their immune and general health. Therefore, there is a constant supply of new chicken preparations containing powerful bacteriostatic EOs. One of the greatest advantages of using EOs is that there have been no reported occurrences of bacteria developing antibiotic resistance as a result of using its components. Another advantage of EOs, beyond their use in immunization, is that they can be administered in a wide range of doses.

Researchers are utilizing cutting-edge technology in their quest to find solutions to the current challenges associated with using EOs as feed in the chicken industry. Encapsulating EOs in edible and biodegradable polymers for coatings or sachets, or combining their volatile components into films or edible coatings, are two examples of how this might be done to improve results. Additionally, a synergistic effect can be generated without compromising the antioxidative capabilities of EOs by combining them at lower quantities with other antioxidants and/or preservation methods. Researchers have shown that chicken farming is especially vulnerable to changes in the surrounding environment. There needs to be a thorough analysis of how volatile EOs influences the ecosystem. The immunomodulatory and anticoccidial effects of EOs have come into greater prominence in recent years. A thorough understanding of the molecular structures of EOs is crucial for extracting their full therapeutic potential.

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