Review Article
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Life Sciences, Medicine and Biomedicine

# Role of essential oils as feed additives in egg production and future perspectives

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**Received**: 23 October 2023; **Revised:** 25 March 2024; **Accepted:** 1 June 2024; **Published:** 4 September 2024
**DOI** https://doi.org/10.28916/lsmb.8.1.2024.140

## ABSTRACT

The use of essential oils (EOs) in poultry production has gained attention due to their potential benefits as natural alternatives to feed additives. However, there is a lack of comprehensive reviews synthesizing the existing literature on the application of EOs in laying hen production. This review paper aims to discuss this research gap by providing a critical review of the current state of knowledge regarding the efficacy, modes of action, and practical considerations of using EOs in layer diets. Through a narrative review of empirical studies, the paper evaluates the effects of various EOs on key performance parameters in laying hens, including egg production, egg quality, feed efficiency, and antioxidative activities. Additionally, the review examines the underlying mechanisms through which EOs exert their beneficial effects, such as antimicrobial, antioxidant, and immunomodulatory properties. In addition, the review identifies and discusses the challenges and limitations associated with the use of EOs in layer production, including issues related to dosage, administration methods, interactions with other feed components, and potential variations in EO composition and quality. By highlighting these challenges, the review offers insights into future research directions and practical recommendations for optimizing the use of EOs in layer production systems. Furthermore, this review paper distinguishes itself from existing literature by providing a comprehensive and critical review of the application of EOs in laying hen production, an area that has received limited attention previously. By synthesizing the current knowledge, this review aims to guide future investigations and facilitate the development of effective and sustainable strategies for incorporating EOs into layer production practices.

***Keywords:*** *Essential oils; laying hens; performance; egg quality; antioxidants and halal*

## INTRODUCTION

The global poultry industry stands at the forefront of agriculture, adapting to meet the escalating demand for poultry driven by population growth and evolving dietary preferences. Remarkably, egg production is central in this industry, a staple in countless global diets, and plays a significant pivotal role within this sector (Jafari et al., 2011; Preisinger, 2018). The industry faces numerous challenges as poultry production continues to expand. The quest for high-quality eggs intensifies alongside the pursuit of inventive and sustainable genetic selection strategies for rapid growth, robust immune systems, and optimal nutrition (Food and Agricultural Organization (FAO), 2017).

However, there are concerns about bacterial resistance to antibiotics commonly used in animal feed, further compounded by consumer demand for natural alternatives to enhance meat and egg production. As a result, there has been a move towards limiting antibiotics as growth promoters (AGPs) and synthetic antioxidants in poultry farming (FAO, 2017). The overuse of antibiotics and synthetic antioxidants in animal production risks the emergence of antibiotic-resistant pathogens and threatens the balance of commensal organisms. This resistance could result in ineffective treatment and economic losses and even serve as a potential source of gene transmission to the human population (Angiolella et al., 2018; Agyare et al., 2019).

In the face of these challenges, the poultry industry is propelled towards exploring alternative solutions, relying on continuous research and innovation in genetics, nutrition, and health. A significant focus has been the application of plant extracts and essential oils (EOs) as natural substitutes for AGPs and synthetic antioxidants (Amerah & Ouwehand, 2016).

EOs have recently garnered increased attention due to their diverse and promising bioactive compounds known for their therapeutic properties. The chemical diversity and health benefits have positioned EOs as potent candidates for various applications (Hashemi & Davoodi, 2010; Ndomou & Mube, 2023). EOs are also being recognized for their safety that they have earned 'Generally Recognized as Safe' (GRAS) status for human consumption from the United States Food and Drug Administration (FDA), provided they are used as intended (United States Food and Drug Administration (FDA), 2023; Lim et al., 2022a; Lim et al., 2022b). This recognition aligns with a global shift towards embracing organic agricultural practices.

Within the poultry industry, EOs have been actively leveraged, particularly in enhancing the productivity of laying hens. These natural alternatives have gained momentum, with a focus on improving laying hen performance, resulting in advancements in growth, feed efficiency, and overall health, as extensively demonstrated in research (Khan et al., 2006; Brenes & Roura, 2010; Gomathi et al., 2018; Cufadar, 2018a; Amiri et al., 2020; Yarmohammadi et al., 2020; Torki & Mohammadi, 2020).

The challenges the modern poultry industry poses necessitate innovative solutions that concurrently prioritize animal welfare and producing high-quality poultry products. The shift from the indiscriminate use of antibiotics and synthetic antioxidants towards natural alternatives like EOs holds excellent promise. As the demand for poultry continues to rise worldwide, embracing such sustainable and natural practices benefits the poultry industry and addresses broader concerns related to antibiotic resistance and food safety. Continuous research and the responsible use of EOs may be a pivotal step towards a more sustainable and health-conscious future for laying hen production.

This review identifies the existing research gaps related to the effectiveness, mechanisms of action, and practical applications of incorporating EOs into layer diets through a critical analysis of the current state of knowledge. It also aims to provide future directions to advance understanding of optimal supplementation strategies for laying hen productivity, health, and egg quality, as outlined in Figure 1. Thus, this review evaluates the role of essential oils (EOs) in laying hens' performance, egg quality, and antioxidative activities. It discusses EO composition and bioactive properties, factors influencing their variability, and their impact on critical outcomes in laying hens, such as feed intake, weight gain, egg production, and feed efficiency, as well as on egg quality traits like shell strength, albumen quality, and yolk pigmentation. Finally, this review comprehensively addresses the limitations of existing studies on the application of essential oils in laying hens, as well as suggests future research directions in this area.

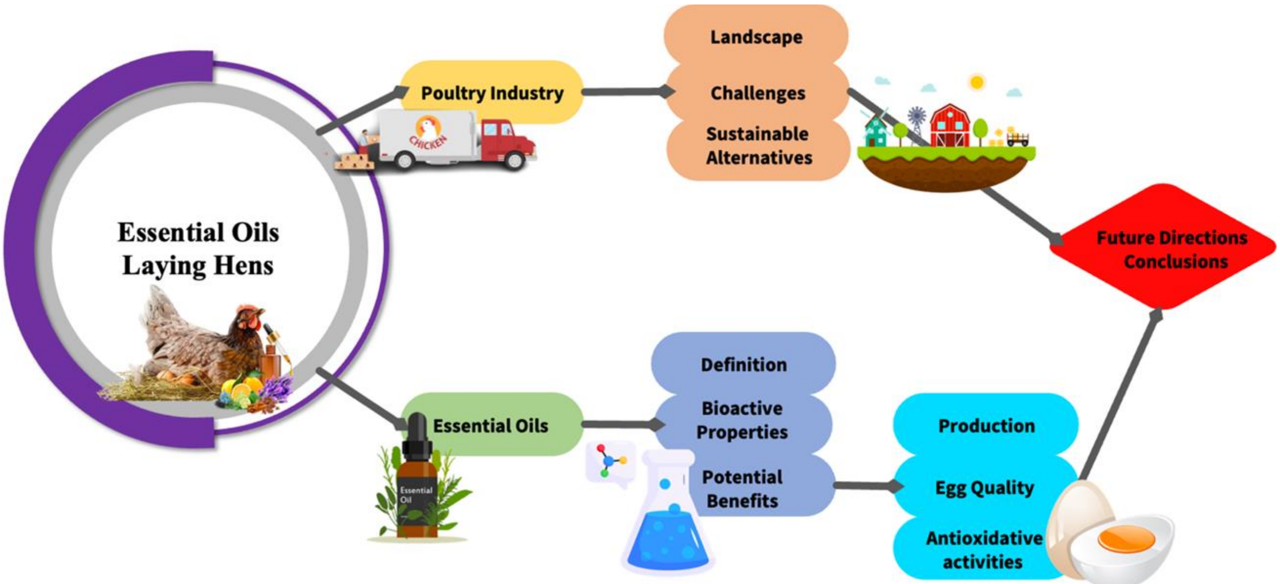
## BACKGROUND AND RATIONALE OF THE POULTRY INDUSTRY

### Landscape of poultry production

Poultry, widely acknowledged for its economical and efficient provision of animal protein, has emerged as a crucial component in contemporary global diets (Miller & Welch, 2013). Over the last several decades, the poultry business has significantly transformed as it has increasingly aligned itself with the United Nations' Sustainable Development Goals (SDGs). With the anticipated global population expected to exceed 9 billion by 2030, the demand for poultry products, including eggs and poultry meats, has escalated (United Nations, 2019). The International Egg Commission (IEC) proactively initiated the Global Project for Sustainable Eggs (GISE) in 2018, which aims to promote continuous enhancements in sustainability practices within the egg business (IEC, 2018). The poultry industry plays a role in advancing several Sustainable Development Goals (SDGs), as it provides nutritional advantages aligned with SDG 2 (Zero Hunger) and SDG 3 (Good Health and Well-Being). This is achieved through the delivery of high-quality protein, essential vitamins, and minerals, contributing to global food security and enhancing overall health (Cheng et al., 2022). The industry also supports educational initiatives aligned with SDG 4 (Quality Education) by providing educational opportunities and resources that empower the community. It also aligns with SDG 8 (Decent Work and Economic Growth) as it fosters economic growth for rural populations. Furthermore, the industry contributes to SDG 12 (Responsible Consumption and Production) by promoting sustainable consumption and production patterns by reducing waste and minimizing resource utilization. This transition highlights the poultry industry's robust commitment to aligning its objectives with the broader goals of sustainable development and global welfare (FAO et al., 2021; FAO, 2022; Chander & Kannadhasan, 2020).

**Figure 1**

*Mind map outlining the objectives of the present review*




*Notes: Mind map outlining the present review, with a particular emphasis on the overarching objective of elucidating the role of essential oils in the performance of laying hens, egg quality, and antioxidative activities.*

## Challenges of modern laying hen production

The poultry industry's remarkable growth is impressive but has challenges. As the industry has scaled up, it has encountered complex issues that demand careful consideration (Dibner & Richards, 2005). These challenges encompass many interrelated factors, as illustrated in Table 1.

Addressing these multifaceted challenges requires a comprehensive approach integrating advancements in animal husbandry, nutrition, disease management, and sustainable practices. A harmonious collaboration among stakeholders, including farmers, researchers, policymakers, and consumers, to collectively work toward a more ethical, sustainable, and resilient laying hen production industry is indispensable (Mench et al., 2011; O'Bryan et al., 2015; Naim et al., 2024).

## Poultry sustainable alternatives

Amidst complex challenges, the global agricultural landscape is transforming towards sustainable and eco-conscious practices (Eyhorn et al., 2019). This profound transformation is driven by heightened consumer awareness and preferences for quality and food safety (Park et al., 2014; McKenzie & Williams, 2015). Regulatory conformance and authorities have responded with more rigorous directives governing the guidelines on antibiotic and additive use in animal feed (Talebiyan et al., 2014; Bartkiene et al., 2020).

Within this evolving context, the poultry industry has embraced a progressive trajectory, championing the visionary stance by embarking on exploring and adopting natural, sustainable alternatives (Eyhorn et al., 2019; Jeni et al., 2021). This aligns with the SDGs of responsible consumption, good health, zero hunger, and decent work (United Nations, 2015). The industry recognizes the pressing need to balance laying hen health and high-quality poultry products (Mirbod et al., 2016). This shift is a thoughtful response underscoring the industry's commitment to ecological responsibility and animal welfare.

In this transformative journey, natural alternatives like essential oils have emerged as powerful allies, reducing antibiotic overuse and mitigating the risks associated with the breed's resistance (Singh et al., 2015; Liu et al., 2017). It offers consumer-desired products without synthetic chemical residues. Proactive sustainability transitions can also mitigate the environmental footprint through eco-friendly production practices (Eyhorn et al., 2019). Furthermore, natural additives may support animal health and welfare in ethical, humane systems (Singh et al., 2015).

**Table 1**

*Challenges of modern laying hen production*

| Challenge | Descriptions | Reference |
|---|---|---|
| Animal Welfare and Ethical Concerns | • The intensification of production methods and the confinement of laying hens in tightly controlled environments have raised ethical questions about the well-being and quality of life for these animals.<br>• Ensuring humane treatment and living conditions for laying hens remains a critical challenge | Verbeke & Viaene, 2000; Mench & Blatchford, 2014; Bos et al., 2018; Busse et al., 2019; Powers et al., 2020; Marchant et al., 2020 |
| Health and Disease Management | • The selective breeding for high-yield strains of laying hens has led to concerns regarding their susceptibility to certain health issues.<br>• Effective disease management strategies are vital to maintaining the health and productivity of these birds while minimizing the use of antibiotics. | Bagust, 1994; Bagust, 2013; Fagrach et al., 2023; Mohd Zaki et al., 2023 |
| Environmental Sustainability | • The poultry industry's substantial environmental footprint, including resource consumption and waste generation, presents formidable challenges to sustainability.<br>• Finding eco-friendly solutions that reduce the industry's impact on the environment is crucial in an era marked by intensified environmental awareness. | Baruwa & Omodara, 2018; Leinonen & Kyriazakis, 2016; Shamsuddoha et al., 2021; Costantini et al., 2021 |
| Antibiotic Resistance | • The widespread and indiscriminate use of antibiotics in poultry farming has contributed to the emergence of antibiotic-resistant bacteria.<br>• This poses a serious threat to both animal and human health, emphasizing the need for responsible antibiotic use and alternative approaches to disease prevention. | Van Boeckel et al., 2019; Jibril et al., 2021; Kim et al., 2021; Farooq et al., 2022; Yap et al., 2022 |
| Chemical Residues, Halal Certification and Food Safety | • The use of synthetic growth promoters and additives in poultry feed has raised elicited concerns about the presence of chemical residues and halal certification status in poultry products.<br>• Ensuring stringent food safety measures is imperative to nurture and sustain consumer trust and confidence | Donoghue, 2003; Rajagopal et al., 2011; Mohammadzadeh et al., 2022 |
| Economic Sustainability | • Balancing the need for increased poultry production with economic viability emerges as a complex challenge.<br>• Factors such as rising production costs, market fluctuations, and competitive pressures all play a role in this complex equation. | Menconi et al., 2014; Rothrock et al., 2019; Jeswani et al., 2019 |
| Regulatory Compliance | • Adhering to evolving regulatory standards and addressing changing consumer preferences for sustainable and ethically produced poultry products adds another layer of complexity to modern laying hen production. | Park et al., 2014; Viator et al., 2017; Rothrock et al., 2019 |

*Notes: Modern laying hen production faces ethical, health, environmental, and economic challenges.*

Continuous research and stakeholder collaboration are still needed to refine sustainable practices. However, the industry's evolutionary leap towards responsible antibiotic use, additives, ethical considerations, and ecology signifies progress. Armed with resilience and innovative prowess, the poultry industry stands poised to redefine sustainability paradigms, fulfilling production requisites while safeguarding the health and well-being of animals, humans, and the environment (Singh et al., 2015; Pashtetsky et al., 2019). Thus, the poultry industry emerges as a pioneering architect of sustainable animal agriculture in the contemporary epoch.

## ESSENTIAL OILS - THE NATURE'S GIFT FOR POULTRY PRODUCTION

### History, concept, and definition of essential oils

EOs are volatile and aromatic compounds extracted from various plant parts, including leaves, flowers, stems, roots, bark, seeds, fruits, wood, and even the entirety of some plants (Bakkali et al., 2008; Krishan & Narang, 2014). These oils have captivated human interest for millennia. While some of their applications have been forgotten over time, extracting these aromatic compounds from plants has been a human endeavor since the beginning of civilization. There are many uses of EOs, including not only their utilization in culinary practices to enhance the flavor and bring the health advantages of food but also their incorporation in the production of feed additives and the creation of fragrances and beauty products.

The term 'essential oil' possesses a captivating historical origin, rooted in the concepts of the sixteenth century. It first originated from the theory of 'Quinta essential' by Paracelsus, an illustrious figure in the medicinal philosophy; the terms reflect a rich tradition of knowledge and discovery (Oyen & Dung, 1999; Krishan & Narang, 2014) Due to their distinct and powerful properties, essential oils, also known as volatile oils, were first referred to as "volatile oils" in the context of pharmacy due to their evanescent nature (Hay & Waterman, 1993). According to Paracelsus, these vital essences that have been meticulously extracted from numerous plants may hold the key to understanding the mechanisms behind powerful and effective medicinal treatments (Van Wyk & Wink, 2017).

Furthermore, the definition of essential oils, as outlined by the International Organization for Standardization (ISO) 9235:2021, provides a comprehensive understanding, stating that they are a "product obtained from a natural plant-origin raw materials through various methodologies such as steam distillation, mechanical processes from citrus fruits' epicarp, or dry distillation, after the separation of the aqueous phase—if present—through physical processes, essential oils maintain their integrity." The ISO definition further emphasizes that "the essential oil may undergo physical treatments without substantial alteration to their intrinsic compositions," underlining the significance of preserving the oil's innate properties throughout the extraction and processing stages (ISO, 2021).

The historical journey of aromatic oils, a captivating odyssey, commenced as early as 10,000 BCE and was employed by the ancient Egyptians for purposes such as fragrance, medicine, and the meticulous mummification rituals, establishing a profound legacy approximately 2600 BCE (Aldred, 1957; Shawn, 2009). In the tapestry of ancient Asian cultures, the Vedas greatly emphasized the essence of fragrances and aromatics for religious rituals and healing reasons (López-Sampson & Page, 2018). Across different eras, civilizations have used essential oils and perfumes for many reasons, such as religious rituals, perfume manufacturing, and medicinal remedies against contagious illnesses. The Greeks, Romans, Jews, Arabs, Phoenicians, Indians, Chinese, Aztecs, and Mayas had a sophisticated society centered upon fragrances (Groom, 1981; Chemat et al., 2012).

Post the Roman Empire's eclipse, the Arabs became the custodians of advanced knowledge and expertise in the fields of scent, resulting in a significant advancement in the realms of scent and perfumery (Shawn, 2009; Zohar & Lev, 2013). As the Middle Ages unfolded, the Crusaders reintroduced the knowledge of perfumes to Europe, weaving threads of ancient knowledge through the fabric of Western societies. In this renewed ambiance, alchemists and monasteries blossomed as guardians and cultivators of olfactory wisdom (Needham & Gwei-Djen, 1962; Zohar & Lev, 2013). Alchemists sought to distill the "elixir of immortality," while monasteries used essential oils and fragrant compounds for medical preparations (Needham & Gwei-Djen, 1962). The Renaissance marked a reinvigoration, a global expansion of the use of essential oils in perfumery and cosmetics, enhancing the era with an aromatic renaissance of its own.

EOs, through their distinctive scents, have been pivotal in the fragrance industry and harnessed for their multifaceted properties, including in the poultry industry (Dhifi et al., 2016; Puvača et al., 2019). Throughout the annals of human history, EOs have been found in varied applications in therapeutic, aromatic, culinary, and feed-addictive contexts. Their enchanting aromas have captivated the senses, and their therapeutic potential has been harnessed to alleviate various diseases.

The composition of EOs is a hallmark of their composition, with each oil comprising a distinctive blend of bioactive compounds. These compounds encompass various chemical constituents, including monoterpenes (hydrocarbon and oxygenated monoterpens) and sesquiterpenes (hydrocarbon and oxygenated sesquiterpenes), each conferring distinct properties and potential benefits to these invaluable extracts (Bakkali et al., 2008; Nazarro et al., 2013; Dhifi et al., 2016; Lim et al., 2022a). Thus, EOs encapsulate a rich tapestry of history, culture, and science, offering a diverse spectrum of applications that persistently evolve in contemporary times.

### Bioactive properties of essential oils

EOs are remarkable natural compounds revered for their bioactive properties and diverse applications in biological systems. The intricate composition of EOs lies in their multifaceted characteristics and broad utility

(Bakkali et al., 2008; Krishan & Narang, 2014; Lim et al., 2022a). These oils, known for their distinctive aromas and centuries-old significance, find purpose in medicine, aromatherapy, cuisine, cosmetics, and feed addiction. This narrative explores the complexity of EOs composition, the factors influencing their variation, and their immense potential in health and well-being, especially in the context of laying hens.

EOs are complex mixtures of bioactive compounds, each contributing to their unique properties. The primary constituents include terpenes, phenols, aldehydes, ketones, alcohols, esters, oxides, and sesquiterpenes (Ríos, 2016; Pavela, 2016; Swamy et al., 2016; Swamy & Sinniah, 2016; Elshafie & Camele, 2017; Lim et al., 2022a). Various factors, such as plant species, geographical origin, climate, and extraction method, influence the exact composition of essential oils. Such variability confers distinct aromas and therapeutic potentials upon each EOs, making a thorough understanding of their chemical compositions for their safe and practical application.

The bioactive properties of EOs harbor many capabilities, extending their influence across various fields, including the health of laying hens. EOs demonstrate potent antimicrobial properties, acting effectively against pathogenic microorganisms by disrupting microbial cell membranes. The lipophilic of EOs components allows them to penetrate the lipid bilayer of bacterial cell membranes, leading to leakage of cellular contents and, ultimately, cell death (Giannenas et al., 2003; Burt, 2004; Adaszyńska-Skwirzyńska & Szczerbińska, 2017; Chouhan et al., 2017; Lim et al., 2022a; Lim et al., 2022b). Compounds such as phenols and terpenes have substantial antioxidant properties, allowing their antioxidants to neutralize free radicals and lessen oxidative damage. Free radicals are unstable molecules that can cause damage to cells and contribute to aging and various diseases (Krishan & Narang, 2014; Abdelli et al., 2017). Furthermore, EOs exhibit anti-inflammatory effects by modulating key pathways and enzymes, suppressing chronic inflammatory responses (Serafini et al., 2020). Such bioactive properties underscore the potential of EOs to promote the health, productivity, and well-being of laying hens naturally and sustainably.

## Potential benefits of essential oils in laying hen production

The use of EOs in poultry production has increased, prompted by the demand for more natural and sustainable products in the food industry (García-Díez et al., 2017). The multifaceted properties of EOs make them valuable tools with diverse roles, such as promoting growth and exhibiting antibacterial, antiviral, and antioxidant activities. They also act as insecticides, digestive stimulants, hypolipidemic agents, immunomodulators, antimycotic agents, antiparasitic agents, and antioxygenic agents (Giannenas et al., 2003; Burt, 2004; Gopi et al., 2014); Adaszyńska-Skwirzyńska & Szczerbińska, 2017; Chouhan et al., 2017; Lim et al., 2022a). With such a broad spectrum of potential benefits, EOs stand poised to significantly influence and shape the future landscape of sustainable and health-conscious poultry production practices. Table 2 shows a summary of the bioactive properties and mechanism of essential oils.

## Performance

In recent years, EOs have garnered increasing attention as feed supplements in the diets of laying hens, driven by the promise of enhanced hen performance and improved quality of eggs. Numerous studies have examined the effects of various EOs, such as dill, nigella, bergamot, thyme, oregano, rosemary, fennel, ginger, sage, cinnamon, star anise, lavender, spearmint, chamomile, and clove oil, on different aspects of laying hens productivity, including egg production, egg weight, egg mass, feed conversion ratio (FCR), and feed intake, often yielding positive results (Torki et al., 2018).

Particular EOs like dill, bergamot, oregano, rosemary, cinnamon, and clove oil have been documented to exert a substantial impact on performance and egg weight (Torki et al., 2018; Abo Ghanima et al., 2020; Şehitoğlu & Kaya, 2021). The performance of hens is attributed to the presence of bioactive compounds in these EOs, which can improve the utilization and absorption of nutrients. Combinations of EOs, such as thyme, rosemary, dill, and peppermint, have also exhibited favorable outcomes in terms of egg weight and mass (Mousavi et al., 2017).

Various EOs, such as dill, bergamot, oregano, rosemary, cinnamon, and mixtures of essential oils, have shown positive effects on FCR in laying hens. This suggests that these oils may enhance the efficiency of feed utilization in hens (Torki et al., 2018; Abo Ghanima et al., 2020). Certain herbs, spices, and their bioactive components stimulate the secretion of saliva, bile, and digestive enzymes, improving digestion (Şehitoğlu & Kaya, 2021). The EOs are believed to possess antibacterial and anti-inflammatory characteristics, which enhance gut health and facilitate nutrient absorption. The study conducted by Torki et al. (2020) discovered that lavender and spearmint EOs had a particular effect on enhancing the size of eggs in laying hens.

## Eggs quality

Improving egg quality has long been a focal point in the poultry industry. Incorporating EOs in laying hens' diets has emerged as a promising strategy to attain this objective. A nuanced understanding of the correlation between diet and egg quality is pivotal. The assessment of various parameters provides invaluable insights into laying hens' overall health and nutritional status, which ultimately affects the eggs producation. In line with this, the use of EOs as feed additives has been shown to provide positive effects on different aspects of egg quality in laying hens, such as egg weight, shell thickness, shell strength, albumen height, yolk weight, albumen weight, egg mass, Haugh unit, and yolk color (Torki et al., 2018; Torki et al., 2020).

**Table 2**

*Bioactive properties and mechanism of essential oils*

| Bioactive Properties | Mechanism | Reference |
|---|---|---|
| Antimicrobial activity | • Possess potent antimicrobial properties against bacteria, fungi, and viruses.<br>• Mechanisms include membrane disruption by terpenoids and phenolics, metal chelation by phenols and flavonoids, and effects on genetic material by coumarin and alkaloids.<br>• Effective against Gram-positive bacteria due to outer membrane's lipopolysaccharide structures.<br>• Promote beneficial microbe growth and reduce pathogenic bacteria, making them valuable in poultry farming. | Giannenas et al., 2003; Burt, 2004; Krishan & Narang, 2014; Adaszyńska-Skwirzyńska & Szczerbińska, 2017; Chouhan et al., 2017; Lim et al., 2022a; Lim et al., 2022b; Alias et al., 2023 |
| Antioxidant activity | • Neutralize free radicals and reduce oxidative damage.<br>• Donate hydrogen or electron to free radicals and delocalize unpaired electron.<br>• Protect biological molecules against oxidation.<br>• Phenolics are more potent antioxidants than vitamins E, C, and carotenoids. | Khan, 2011; Krishan & Narang, 2014; Abdelli et al., 2017; He et al., 2017; Yu et al., 2018; Cheng et al., (2022). |
| Anti-inflammatory Properties | • Essential oils reduce gut inflammation and improve nutrient absorption.<br>• Terpenoids and flavonoids in essential oils suppress inflammatory prostaglandin metabolism.<br>• Plants like chamomile, marigold, liquorice, and anise have anti-inflammatory potential. | He et al. 2017; Yu et al., 2018; Serafini et al., 2020; Cheng et al., 2022 |
| Immunomodulatory Effects | • Essential oils modulate immune response, potentially enhancing disease resistance.<br>• Garlic's immunomodulatory effect is due to increased production of interleukins, TNF-α, and INF-γ.<br>• Garlic boosts phagocytosis, macrophage metabolism, antioxidant function, and antigen-presenting cells. | Lee et al., 2003; Attia et al., 2019 |

*Notes: Essential oils exhibit antimicrobial, antioxidant, anti-inflammatory, and immunomodulatory activities.*

Research conducted by Torki et al. (2018), Torki et al. (2020), and Abo Ghanima et al. (2020) has shown that certain EOS, including spearmint, oregano, rosemary, sage, cinnamon, and star anise, as well as a combination of multiple EOs, have a significant effect on the egg's weight and mass. The bioactive components inherent in these oils are believed to enhance the absorption and utilization of nutrients, leading to improved egg development. EOs like fennel, ginger, rosemary, thyme, and blends of several oils have shown beneficial impacts on the thickness and durability of eggshells (Nasirifar et al., 2010; Mousavi et al., 2017). This implies their capacity to enhance calcium and magnesium metabolism, enhancing shell quality. According to Zhao et al. (2011), improving egg quality of laying hens supplemented with EO may be due to many causes, such as antioxidant and antibacterial properties, increased blood circulation, elevated production of digestive enzymes, and reduced feed oxidation.

Several studies on EOs, such as bergamot, thyme, rosemary, oregano, clove oil, and cinnamon identified to exert positive effects on albumen quality metrics, including albumen height and Haugh unit score (Bölükbasi et al., 2010;

Abo Ghanima et al., 2020; Şehitoğlu & Kaya, 2021). Their antioxidative characteristics aid in preserving the quality of albumen by mitigating oxidative processes.

EOs have also shown positive benefits on both yolk color and weight, enhancing the overall internal quality of eggs (Torki et al., 2018). Multiple studies have shown a clear correlation between the yolk color and the dietary presence of xanthophylls, like lutein and zeaxanthin. Concurrently, the antioxidant properties of pigments like carotene and xanthophyll emerge as contributors to this relationship by offering protection to lipids from oxidation, fostering the development of a vibrant yolk color (An et al., 2010; Gul et al., 2012).

**Antioxidative activities**

The modern poultry sector constantly seeks ways to enhance the well-being and efficiency of laying hens, ensuring the eggs remain high-quality and safe for consumers. A significant challenge within this intricate biological framework is oxidative stress. Laying hens produce free radicals and reactive oxygen species as natural byproducts of their metabolism and egg production (Zhang et al., 2010). While these chemicals are integral to metabolic functions, their overproduction may cause oxidative damage to cells, tissues, and egg components (Khan, 2011). To counteract oxidative stress, laying hens depends on a strong internal defense system consisting of antioxidant enzymes such as superoxide dismutase, glutathione peroxidase, and catalase (Surai et al., 2019). Supplementing one's diet with antioxidants offers supplementary assistance. EOs have shown significant promise as natural antioxidant supplements in the diet of laying hens.

Multiple research investigations have shown that dietary EOs effectively enhance the antioxidant levels in tissues such as serum, egg yolk, and meat in laying chickens. EOs such as oregano, rosemary, sage, star anise, and blends comprising carvacrol, thymol, and cinnamon have shown a significant increase in the serum antioxidant capacity in laying hens, as evidenced by studies conducted by He et al. (2017), Yu et al. (2018), and Cheng et al. (2022). This demonstrates their capacity to decrease systemic oxidative stress.

Star anise, oregano, rosemary, and blends containing carvacrol, thymol, and nano-silica have shown positive benefits on antioxidant levels in egg yolk in laying hens, according to studies conducted by Yu et al. (2018) and Cheng et al. (2022). The beneficial phenolic chemicals in these oils are believed to be transferred to the yolk and directly enhance antioxidant activity. This aids in preserving the freshness and inhibiting the decay of the product. The inclusion of carvacrol and thymol in EOs combinations has been seen to enhance the activity of antioxidant enzymes such as superoxide dismutase and glutathione peroxidase in the liver and poultry meat of laying hens (Cheng et al., 2022). These findings signify their potent ability to fortify the natural antioxidant defense systems of the body, culminating in improved and refined meat quality.

The antioxidant properties of EOs are primarily attributed to phenolic compounds such as carvacrol, thymol, eugenol, and rosmarinic acid. These compounds can neutralize free radicals and activate cellular routes conducive to antioxidant activities. Integrating these EOs into the dietary regimes of laying hens may assist in reducing oxidative stress, which has detrimental effects on their health, egg quality, and shelf-life. Further investigation is necessary to ascertain the most effective amounts of essential oils to enhance antioxidant properties.

Current data substantiates the use of EOs in the meals of laying hens as a feasible natural approach to improve antioxidative status. EOs counteract lipid oxidation, enhance internal enzymatic antioxidant activity, fortify oxidative defences, and to improve egg quality by directly scavenging free radicals. Additional studies should persist in exploring the most effective methods of supplementing. Essential oils have great potential as sustainable natural alternatives to enhance contemporary laying hens' health, productivity, and product quality. Table 3 shows the effect of essential oil on laying hens.

## LIMITATIONS OF THE STUDY

While the reviewed literature points towards the promising potential of using EOs as natural feed additives in laying hen diets, several limitations should be acknowledged.

The effects of essential oils appear to be influenced by multiple factors such as the specific EO used, its composition, dosage levels, supplementation duration, diet composition, environmental conditions, hen breed or age, and physiological status (Adaszyńska-Skwirzyńska & Szczerbińska, 2017; Torki et al., 2018; Abo Ghanima et al., 2020). These variations make it challenging to derive definitive, universally applicable recommendations. More standardized approaches are needed to isolate better and understand the impacts of EO supplementation (Xiao et al., 2022).

Most existing studies have been conducted over relatively short experimental periods ranging from just a few weeks to a couple of months (Torki et al., 2020). However, laying hens have long productive cycles spanning several months to years. The long-term effects of persistent essential oil supplementation remain unclear. It is unclear whether the observed benefits would be sustained, diminished or even reversed over lengthier durations. Studies with extended feeding periods covering entire laying cycles are warranted (Arulnathan et al., 2024).

From a mechanical perspective, while the studies associate essential oil supplementation with enhanced parameters, there is still a need for more research into elucidating the specific biological mechanisms through which different oil compounds exert their effects on avian physiology, metabolism, and egg biochemistry. With a deeper understanding of these pathways, it becomes easier to optimize and fine-tune interventions.

So far, the majority of research has concentrated on examining individual EOs separately when applied to poultry. However, commercial EOs blends that combine multiple oils are increasingly gaining popularity. Research on the combined effects, synergies, and potential antagonistic interactions between oil components must be completed. Systematic studies in this area could inform the development of more productive combinations. Overcoming these limitations will be crucial to translating findings into practical, sustainable, and optimized essential oil utilization strategies.

**Table 3**

*Effect of essential oils on laying hen*

| Essential oils | Experimental period (week) | Key findings | Citation |
|---|---|---|---|
| Dill | 11 | Decrease FCR and egg weight, Improved in egg production | Torki et al., 2018 |
| Nigella sativa | 10 | Shown a significant effect on egg index. No significant on FI, FCR, egg production and egg weight. decreased triglyceride and cholesterol. | Bölükbasi et al., 2009 |
| Bergamot | 8 | Improve FCR, egg production and egg weight, Haugh Unit Score. Increase in eggshell strength. | Bölükbasi et al., 2010 |
| Thyme | 20 | No significant on FI, FCR, Egg production and egg weight. | Arpášová et al., 2015 |
| | | Improved egg weight and FCR, | |
| Oregano | 20 | No significant on FI, FCR, Egg production and egg weight | Arpášová et al., 2015 |
| | 7 | Improved production rate, egg weight, FCR and improved nutrient absorption. | He et al., 2017 |
| | 8 | Improve egg-production, performance and decrease FCR. | Gao et al., 2022 |
| | 12 | No effect on performance and eggshell quality parameters of laying hens | Cufadar, 2018a |
| | 8 | Improving performance, egg quality, and reducing oxidative stress | Gul et al., 2019 |
| Rosemary | 8 | Improved on egg production and weight, egg quality, FI and FCR, Cholesterol, liver and kidney functions, immunity, and antioxidant parameters. | Abo Ghanima et al., 2020 |
| | 12 | No effect on performance and improve Eggshell thickness and Eggshell breaking strength | Cufadar et al., 2018b |
| | 16 | improved egg weight and feed conversion, Reduce E. coli concentration | Bölükbaşi et al., 2008 |
| | 12 | Improved egg weight and feed conversion, lower E. coli concentration | Bölükbaşı et al., 2008 |
| | 11 | Improve egg production and egg weight | Torki et al., 2018 |
| Fennel | 6 | Improved egg shell weight and thickness | Nasiroleslami & Torki 2010 |
| Ginger | 6 | Improved egg shell weight and thickness | Nasiroleslami & Torki 2010 |
| Sage | 12 | improved egg weight and feed conversion Haugh unit, lower E. coli concentration | Bölükbaşi et al., 2008 |
| Cinnamon | 48 | Improved on egg production and weight, egg quality, FI and FCR, Cholesterol, liver and kidney functions, immunity, and antioxidant parameters | Abo Ghanima et al., 2020 |

**Table 3** *(continued)*

| Essential oils | Experimental period (week) | Key findings | Citation |
|---|---|---|---|
| | 8 | Improve production, egg weight, egg mass, and FCR | Torki et al., 2014 |
| Star anise | 8 | Improve FI and egg mass, enhanced antioxidative status in serum, liver, and yolk | Yu et al., 2018 |
| Lavandula | 14 | Improve FCR | Torki et al., 2020 |
| Spearmint | 14 | Improve egg production and egg mass | Torki et al., 2020 |
| Chamomile | 16 | Improve egg weight | Poráčová et al., 2007 |
| Clove Oil | 28 | Improved FCR and increased the egg production | Şehitoğlu & Kaya, 2021 |
| Combination of peppermint essential oil and thyme essential oil | 8 | Increased egg performance, egg mass, FCR, egg shell thickness and Haugh unit | Akbari et al., 2016 |
| Combination of carvacrol, thymol essential oil and palygorskite | 8 | Improved the egg production, enhanced antioxidation, ameliorated egg quality. | Cheng et al., 2022 |
| Combination of thyme, black cumin, fennel, anise and rosemary essential oil | 21 | Improve egg weight and egg mass and eggshell thickness | Olgun, 2016 |
| Combination of zink with cinnamon essential oil | 8 | Improve production, egg weight, egg mass, and FCR | Torki et al., 2014 |
| Combination of thyme, rosemary, dill and peppermint. | 11 | Improve shell weight, shell strength, shell thickness and serum malondialdehyde | Mousavi et al., 2017 |
| Combination of carvacrol, thyme, cinnamaldehyde combined and carrier nanoscale silica | 8 | Improve the eggshell quality and serum antioxidant capacity and reduce egg-breaking rate. | Xiao et al., 2022 |
| Combination of cinnamaldehyde and thymol essential oil | 5 | Improve growth performance and production efficiency and improve immune response | Attia et al., 2019 |

*Notes: Individual or mixtures of essential oils exhibited various beneficial effects on the health performance, production and egg quality of laying hens.*

## FUTURE DIRECTIONS AND CONCLUSIONS

Essential oils (EOs) play a crucial role in enhancing the nutrition of laying hens, offering various benefits such as performance enhancement, antioxidant properties, antimicrobial activities, hypolipidemic agents, and anti-inflammatory actions. However, the efficacy of EOs is subject to variability, influenced by factors such as their specific type and dosage and the general health of the hens. EOs can significantly influence feed intake and the overall weight of laying hens. Numerous studies have shown positive impacts on nutrient performance, egg quality, and reducing fatty acids and cholesterol levels. Through the strategic integration of EOs in the diets of laying hens, EOs can improve production outcomes while mitigating potential adverse effects on the hens. This alignment of scientific inquiry with practical application highlights the potential of EOs as a valuable tool for fostering sustainable and health-conscious poultry production practices. Further research and exploration are needed to maximize the benefits of laying hen vitality and egg quality. This will facilitate a refined comprehension of EOs and their precise supplementation levels, thereby maximizing benefits for laying hens and egg quality and advancing the poultry industry in a sustainable and health-conscious direction.

## AUTHOR CONTRIBUTIONS

The article writing, visualization and conceptualization were carried out by Rosli Muhammad Naim, Shirley Gee Hoon Tang and Mohd Nizam Lani. Validation was completed by Shirley Gee Hoon Tang, Mohd Nizam Lani and Maisarah Abdul Mutalib. Funding acquisition was managed by Shirley Gee Hoon Tang and Indang Ariati Ariffin. Review and editing were performed by all authors. Supervision was provided by Shirley Gee Hoon Tang and Indang Ariati Ariffin. All authors have read and agreed to the published version of the manuscript.

## ETHICS APPROVAL

Not applicable.

## FUNDING

The research is funded by the Ministry of Higher Education Malaysia (MOHE) under the Fundamental Research Grant Scheme (FRGS), project code FRGS/1/2019/WAB01/MSU/02/1.

## CONFLICTS OF INTEREST

The authors declare no conflict of interest in this work.

## ACKNOWLEDGEMENTS

Heartfelt gratitude is extended to the Ministry of Higher Education Malaysia (MOHE) for their generous funding support through the Fundamental Research Grant Scheme (FRGS) under Project code: FRGS/1/2019/WAB01/MSU/02/1. Additionally, our sincere appreciation goes to the Management and Science University (MSU), Universiti Malaysia Terengganu (UMT), and University Kebangsaan Malaysia (UKM) for their unwavering support and encouragement, which played a pivotal role in the successful execution of this project.

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**Citation:**
Muhammad Naim, R., Lani, M. N., Tang, S. G. H., Abdul Mutalib, M., Ariffin, I. A., Tang, H. C., Yong, S. T., & Loh, T. C. (2024). Role of essential oils as feed additives in egg production and future perspectives. *Life Sciences, Medicine and Biomedicine*, *8*(1). https://doi.org/10.28916/lsmb.8.1.2024.140

**Life Sciences, Medicine and Biomedicine**
**ISSN: 2600-7207**