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Review

# Basil Essential Oil in Poultry Production and Poultry Industry: Applications and Future Perspectives

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**Abstract**

Basil essential oil (BEO) has emerged as a promising natural alternative to antibiotic growth promoters in poultry production. BEO has shown antimicrobial, antifungal, anticoccidial, antioxidant, and insecticidal properties. BEO exhibits broad antimicrobial activity against Gram-positive and Gram-negative pathogens, and modulates gut microbiota by decreasing *Escherichia coli* and *Staphylococcus* spp. Anticoccidial effects include reduced oocyst shedding, improved intestinal morphology, and downregulation of pro-inflammatory cytokines. Antifungal activity reduces fungal load and inhibits Aspergillus spp., with implications for control spoilage and aflatoxin risk. BEO at a concentration of 40 ppm was effective in preventing E. tenella invasion, showing an average reduction in invasion by 36% in primary chicken epithelial cells. Antioxidant benefits include enhanced intestinal and systemic antioxidant status. Advanced nanoformulation technologies, particularly nano-encapsulation, have substantially overcome several limitations for BEO application in poultry. Further research is still required to assess the efficacy of nano-encapsulated BEO for enhancing overall poultry industry productivity. This review synthesizes current evidence on BEO integration in the poultry production sections, from nutrition and disease control to product preservation and farm hygiene, and evaluates technological solutions that address formulation barriers. Moreover, it discusses critical research gaps and proposes future directions for enhancing BEO applications in sustainable poultry production systems.

**Keywords:** basil essential oil; poultry; biological activities; *Ocimum basilicum* L.; nanoformulations

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## 1. Introduction

Antibiotic growth promoters in poultry diets have been increasingly restricted in recent years owing to food safety, environmental pollution, human health concerns, and prevention of the development of antibiotic-resistant bacteria [1]. Consequently, animal

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scientists and producers have explored alternative strategies to enhance growth, improve meat quality, promote animal health, and safeguard human health.

Essential oils (EOs), the principal aromatic components found in herbs and spices, serve as natural substitutes for antibiotic growth stimulants in poultry feed owing to their antibacterial, antifungal, antiparasitic, and antiviral activities [2,3].

Integrating EOs into poultry diets presents an environmentally friendly and economical approach to improve food and nutrition security while promoting consumer health [4,5]. Moreover, EOs have long been used and investigated as potential antimicrobial agents, possibly mediated through complex and multifaceted mechanisms of action [6]. Experimental evidence suggests that they may contribute to bactericidal, fungicidal, antiparasitic, insecticidal, and virucidal activities; however, the extent of these effects varies across studies and depends on factors such as chemical composition and experimental conditions. Additionally, it has also been documented that EOs exhibit food preservation properties by mitigating harmful bacteria such as *Salmonella* and *Escherichia coli* in the meat and final poultry products [7]. EOs have shown potential in the prevention and control of zoonotic diseases [3]. Recently, the use of EOs in broiler chickens has gained interest because they provide additional benefits, such as appetite stimulation, improvement of digestive enzyme production, and activation of immune responses [5,8–10].

Among the various essential oils used in the poultry sector, basil essential oil derived from *Ocimum basilicum* L. has attracted considerable scientific interest. This is largely due to its abundant phytochemical content, particularly linalool, eugenol, and methyl chavicol, which are known for their strong biological effects [11]. The *Ocimum* genus includes around 150 species, with sweet basil (*Ocimum basilicum*) that can be integrated into poultry production systems to enhance microbiologically safe food products [12].

Although EOs possess valuable bioactive properties, their practical application is limited by volatility, poor water solubility, low intestinal absorption, and environmental sensitivity [13]. The integration of nanotechnology with essential oil delivery represents a significant technological leap to overcome these challenges [14]. Nanoformulation approaches, such as microencapsulation, nano-emulsions, and nanoparticle-based delivery systems, have demonstrated the capacity to enhance stability, protect against degradation, control release, and improve the bioavailability of BEO in the avian gastrointestinal tract [15,16].

BEO exhibits several distinctive features that distinguish it from commonly studied essential oils such as oregano and thyme. One of its most notable characteristics is its pronounced chemotype diversity, particularly the presence of linalool, estragole, and citral chemotypes, which provides a broader chemical variability compared to the relatively more uniform phenolic profiles (carvacrol and thymol) of oregano and thyme oils [17]. This diversity may contribute to a wider range of biological activities.

Moreover, BEO has shown notable potential in antifungal applications, including the ability to inhibit both fungal growth and mycotoxin production, in some cases with efficacy exceeding that of certain commercial antifungal agents [18]. While oregano and thyme essential oils are generally recognized for their broad-spectrum antibacterial activity, basil oil appears to offer specific advantages in antifungal activity and targeted antimicrobial effects against selected pathogens [17]. However, the use of this essential oil as a food preservative is often constrained by sensory limitations because of its strong smell, which affects the food organoleptic properties negatively [19]. Additionally, the use of conventional antimicrobial strategies in the food industry is often limited due to concerns regarding their potential effects on food quality and human health. In this context, encapsulation of BEO into yeast cell wall enables the development of edible antimicrobial coating suspensions for effective pathogen control on real food matrices [20].

This review critically synthesizes current research on BEO in poultry production, emphasizing its applicability across the entire production chain from farm to fork. Unlike broad reviews on EOs, it focuses specifically on BEO, integrating evidence on its diverse biological activities, including anti-inflammatory, antioxidant, antimicrobial, and antifungal effects, making it a promising alternative to antibiotics in poultry production. Despite its demonstrated benefits, key knowledge gaps remain regarding long-term efficacy, stress mitigation, productivity outcomes, and toxicity, highlighting the need for a focused review on BEO in poultry production and industry practices.

## 2. Chemical Composition and Bioactive Compounds of Basil Essential Oil

### *2.1. Major Bioactive Constituents*

Basil (*Ocimum basilicum* L.) (Lamiaceae), known as the king of herbs and sweet basil, is cultivated worldwide for culinary, industrial, and medicinal purposes [21]. Basil essential oil is typically extracted from aerial parts of the plant through steam distillation or hydrodistillation, with yields ranging from 0.5% to 2.0% depending on cultivar, growth conditions, and extraction methodology [22]. Different parts of the *Ocimum basilicum* L plant have essential oils with different compositions. These differences show that the plant has various chemical types. Quantitative analysis showed that flowers (99.03%) contained the highest essential oil concentration, followed by stems (97.66%), and leaves (95.04%) [23]. Linalool, a monoterpene alcohol, typically constitutes the predominant component in sweet basil chemotypes, ranging from 40% to 70% of total oil composition. Other significant constituents include methyl chavicol (estragole), eugenol, 1,8-cineole, and various compounds, may also be present in significant concentrations [23–25]. This chemical diversity contributes to the broad-spectrum biological activities observed in BEO applications.

### *2.2. Chemotypes Diversity*

Basil (*Ocimum basilicum* L.) exhibits significant genotypic variability in essential oil production, resulting in distinct chemotypes with different chemical compositions. This variability in volatile and aromatic compounds is associated with diverse potential effects in poultry production, particularly in meat preservation and quality enhancement. Targeted selection of specific chemotypes can optimize functional benefits in poultry products; for example, Chemotype 2 has demonstrated validated effectiveness as a natural preservative for chicken meat [26]. This chemical diversity provides poultry producers with multiple options for natural preservation and quality enhancement, enabling selection based on specific production needs and desired flavor profiles. Moreover, the extraction technique plays a critical role in shaping the phenolic profile of the extracts [27]. Interestingly, Basil cultivars have different chemotypes based on their phenolic acid profiles, with cultivars high in caffeic acid forming a distinct cluster with the highest total phenolic content and strongest antioxidant properties [28]. The rich composition of phenolic and volatile compounds highlights the potential of basil extracts as valuable natural antioxidants and antimicrobial agents [27].

The chemical composition of BEO is highly variable and influenced by multiple factors, including genetic background, extraction methods [19], environmental conditions such as seasonal variation and growing region [29], cultivation conditions, plant growth stages [30], and variations across different cultivars [29,31] (see Supplementary Table S1). Understanding the phytochemical profile is essential for standardization and quality control in commercial applications, as variations in composition can significantly affect efficacy and consistency of biological outcomes [29,32].

## 3. The Antimicrobial Activities of Basil Essential Oil

### *3.1. Modulation of Gut Microbiota*

Gut microflora significantly influences host immunity, health, and growth performance through complex interactions with nutrient utilization and the development of the host's gastrointestinal system [33]. Consequently, alternative strategies have focused on inhibiting the proliferation of pathogenic bacteria and modulating the composition of indigenous microbiota to enhance the health, immune function, and overall performance [34]. Recent studies have explored the antimicrobial activity of BEO against common poultry pathogens [35–37]. The antimicrobial spectrum of BEO extends to both Gram-positive and Gram-negative bacteria. It enhances the gut microbiome and may indirectly augment immune system function through the elimination of pathogenic microorganisms, as it reduces the population of *E. coli*, while promoting the growth of Lactobacillus spp. and demonstrating selective antimicrobial activity [38,39]. The ability to suppress pathogenic bacteria while enhancing beneficial microbiota represents an important advantage over broad-spectrum antibiotics that indiscriminately eliminate intestinal bacteria (Figure 1). In broiler intestines, it reduces harmful bacteria, *E. coli* and *Staphylococcus* species, while enhancing the proliferation of *Lactobacillus* bacteria [36]**.** BEO showed variable antibacterial activity depending on plant part and bacterial species. Flower oil exhibited the strongest activity against *S. aureus*, whereas leaf oil showed the weakest effect against *E. coli*, indicating greater susceptibility to *S. aureus*. Overall, flower oil demonstrated higher antibacterial potential than leaf oil [40]. Additionally, coagulase-positive Staphylococcus species were the most susceptible to the antimicrobial action of the essential oil [41].

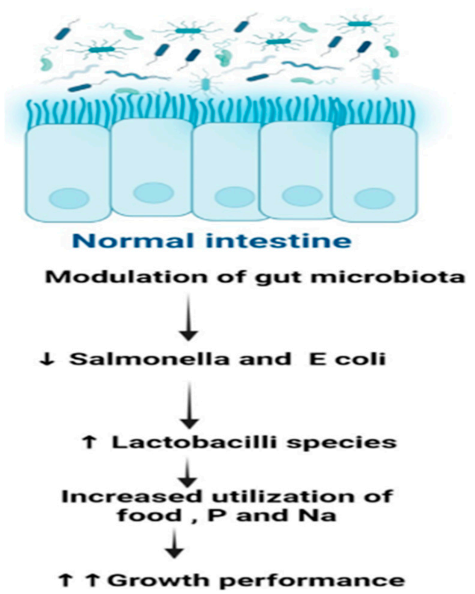


**Figure 1.** Modulation of Gut Microbiota by Basil Essential Oil.

The broad-spectrum antibacterial activity of BEO against antibiotic-resistant *Salmonella* species isolated from poultry farms addresses a critical concern for food safety and public health [42]. *Salmonella* contamination in poultry products represents a leading cause of foodborne illness, and the emergence of antibiotic-resistant strains has complicated control efforts [43].

Several studies have investigated the use of essential oils to prevent necrotic enteritis, a devastating disease caused by *Clostridium perfringens* [44,45]. The synergy of antimicrobial properties and intestinal health benefits provides robust defense against enteric diseases, which lead to substantial economic losses in poultry farming [46]. Research on the

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use of BEO for controlling enteric infections in poultry, whether alone or in combination with organic acids, probiotics, or prebiotics, remains limited, despite its well-documented antimicrobial activity.

*3.2. Anticoccidial Properties*

Coccidiosis, caused by *Eimeria* species, represents one of the most economically significant parasitic diseases in poultry production, with global economic losses. Research suggests that BEO and other phytogenic compounds demonstrate anticoccidial activity through various mechanisms, such as antimicrobial effects, immune modulation, and enhancement of intestinal integrity. Studies have shown that BEO can reduce oocyst shedding, improve gut morphology, and regulate inflammatory cytokines, thereby highlighting the potential of plant-derived extracts to bolster host resistance against Eimeria infections [47–49].

BEO has shown the potential to prevent and treat coccidial infection in broilers at different dosages [50]. Moreover, BEO, along with its bioactive constituent linalool, has been found to effectively reduce sporozoite invasion and change the morphology of sporozoites [51]. The mechanisms of anticoccidial action involve multiple pathways. Scanning electron microscopy revealed that BEO induced morphological anomalies in *E. tenella* sporozoites, characterized by a reduction in area, perimeter, and length [51]. These structural alterations likely compromise sporozoite viability and invasive capacity, contributing to reduced infection establishment.

The immunomodulatory effects of BEO, which significantly reduced the expression of pro-inflammatory cytokines (IL-8, IL-1β, IL-6) in infected chicken epithelial cells [51]. This anti-inflammatory action may protect against immunopathology associated with coccidial infection, which contributes substantially to production losses even when parasite loads are controlled.

BEO and ionophores differ fundamentally in their mechanisms of action, antimicrobial spectrum, and practical applications. Ionophores act specifically against coccidian parasites by disrupting ion homeostasis, providing predictable efficacy, consistent dosing, and relatively low cost, although they exhibit limited antibacterial activity [52,53]. Evidence consistently indicates that ionophores remain superior in terms of anticoccidial efficacy, cost-effectiveness, and performance under high challenge pressure, particularly in conventional production systems. In contrast, BEO exhibits broad-spectrum antimicrobial activity against bacteria, fungi, and parasites, in addition to modulating host immunity and oxidative stress [38]. It also offers practical advantages, including the absence of withdrawal periods, compatibility with organic and antibiotic-free production systems, and a lower likelihood of resistance development. However, its efficacy may vary due to differences in chemical composition, production conditions, and storage stability, and it is associated with higher inclusion costs compared to ionophores [54]. The optimal choice depends on production system goals, regulatory constraints, and market positioning, with emerging evidence supporting strategic rotation or combination approaches.

Overall, ionophores remain the most economically efficient option for conventional producers targeting commodity markets. In contrast, BEO represents a viable alternative for producers aiming to access premium markets, where its functional and regulatory advantages may offset higher costs. Therefore, the selection between these strategies should be guided by production goals, disease pressure, regulatory requirements, and market positioning, with emerging evidence supporting the potential use of integrated or rotational approaches.

Accordingly, the available literature indicates that critical knowledge gaps remain, particularly regarding long-term commercial efficacy, optimal dosing strategies, and the effectiveness of BEO against different *Eimeria* species. Most research has focused on specific broiler strains or single *Eimeria* species, limiting its applicability to commercial poultry production systems characterized by diverse breeds and mixed infections. Further research is required to establish standardized application protocols and assess economic feasibility, thereby supporting its practical adoption in commercial broiler production and enabling more precise recommendations.

### *3.3. Anti-Fungal Properties*

The antifungal properties of BEO are primarily attributed to its main components, particularly methyl eugenol. High concentration of methyl eugenol demonstrates significant antifungal activity against dermatophytes, filamentous fungi, and yeasts [55]. BEO at 0.5 g/kg feed significantly reduced the total fungal load in the Japanese quail [31]. Comparative studies have evaluated BEOs of three species of Ocimum, estragole (methyl chavicol rich species) mainly accounts for its strong antifungal and anti-aflatoxigenic activity against Aspergillus flavus, making it a potential natural food preservative [35,56]. BEO demonstrated strong inhibitory activity against various *Aspergillus* species and is recommended as a natural, eco-friendly antimicrobial in poultry food to inhibit fungal growth and aflatoxin production [33–35]. Further studies are needed to evaluate the efficacy of BEO against a broader range of fungal species under various environmental conditions. Additionally, research should focus on optimizing the formulation and application methods of these oils for their practical use in food preservation and storage. The potential synergistic effects of combining BEO with other natural antifungal agents should also be explored to enhance their overall effectiveness in controlling fungal contamination.

BEO components such as linalool, eugenol, and methyl chavicol can either work together or function separately to disrupt cell membranes, inhibit critical fungal enzymes, and interfere with various cellular activities, such as energy production, by inhibiting ATP synthesis (Figure 2). Additionally, these components can coagulate cellular contents, lead to cytoplasmic leakage, and ultimately result in cell death through apoptosis or necrosis [57,58]. Targeting multiple sites at once decreases the chances of resistance developing, compared to single-target antimicrobials, representing a significant advantage for long-term sustainability.

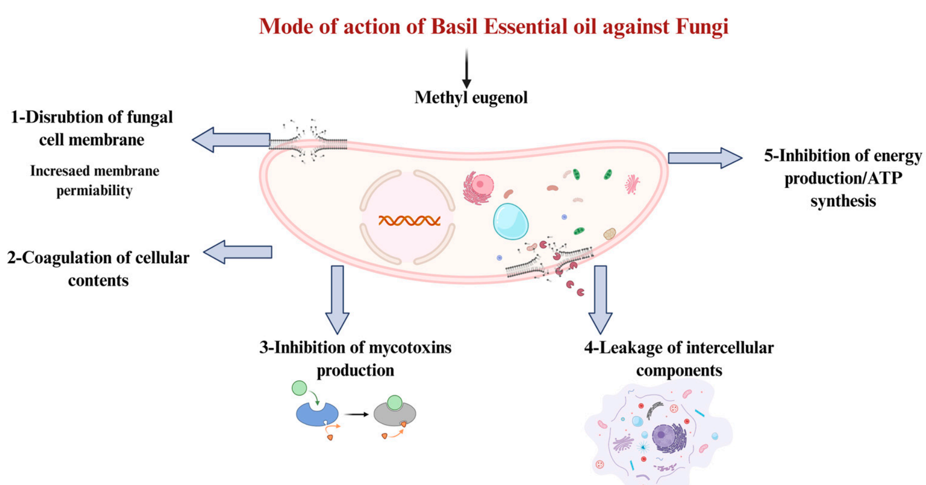


**Figure 2.** Antifungal Mechanisms of Basil Essential Oil "Adapted from Maurya et al. [59], CC BY 4.0". BEO exhibits antifungal activity by targeting multiple cellular sites. It disrupts the fungal plasma membrane, leading to loss of membrane integrity. It also affects mitochondrial activity by reducing membrane potential and ATP production, resulting in energy depletion. Additionally,

basil essential oil induces DNA/RNA damage and alters gene expression, interfering with cell cycle progression and fungal growth. These combined effects ultimately lead to growth inhibition and cell death.

### *3.4. Mechanisms of Antimicrobial Action*

BEO exhibits antimicrobial properties through various mechanisms that result in a broad-spectrum activity. The primary mechanism involves disrupting the integrity of microbial cell membranes through the interaction of lipophilic BEO components with membrane lipids [12]. As a result of this interaction, the membrane becomes more permeable, causing cellular contents to leak out, disrupting ion gradients, and eventually leading to cell death.

Linalool, the predominant component in most BEO chemotypes, a fragrant monoterpene alcohol commonly identified as a key antimicrobial agent. It is found in household cleaners, food additives, and exhibits significant inhibitory effects on resistant strains of *Staphylococcus*, *Enterococcus*, and *Pseudomonas* [60]. The hydroxyl group in linalool's structure contributes to its antimicrobial activity through interaction with membrane proteins and disruption of cell membranes [61].

Secondary mechanisms through which linalool has demonstrated antibacterial activity against both Gram-negative and Gram-positive bacteria include interference with microbial metabolism and enzymatic systems [62]. Studies have suggested that linalool can become a preservative of food by destroying the cell membrane, reducing the membrane potential (MP), causing leakage of alkaline phosphatase [63], destroying the cell structure and expelling the cytoplasmic content (DNA, RNA, and proteins), resulting in bacterial cell death [64–66].

Its activity was tested in vitro against *E. coli* and *S. aureus*, showing promising anti-adherence effects against *S. aureus* without any diffusion of linalool [67]. This indicates the potential of linalool as a natural preservative and eco-friendly method for disinfecting poultry farms and processing units as shown in Table 1. Besides possible reduction or elimination of enteropathogens, linalool might also protect feed from spoilage by insects or fungi, and reduce insect infestation in the poultry house [11].

**Table 1.** Applications of Linalool in Poultry Production.

| Form Used | Target Organism | Applications | References |
|---|---|---|---|
| Covalently immobilized in UV-cured thiol–ene polymer network | *S. aureus*, *E. coli* | ✓ Poultry equipment coatings,<br>✓ disinfection processing units | [67] |
| Free linalool blended with essential oils | *S. aureus*, *E. coli*, *P. aeruginosa* | ✓ Synergistic and additive enhancement against bacteria and fungi | [68] |
| Free linalool | *P. aeruginosa* | ✓ Food preservation<br>✓ Shelf life extension | [64,69] |
| linalool vapor | *E. coli* | ✓ Egg fumigation | [66] |
| Free linalool | *S. putrefaciens* | ✓ Food preservation | [65] |

Additionally, BEO is rich in phenolic compounds, which are effective in preventing bacterial proliferation. These compounds affect microorganisms through several mechanisms, including modification of microbial cell membrane permeability. Finally, they may attach to enzymes and inhibit their activity [70].

## 4. Antioxidant Properties of Basil Essential Oil

Oxidative stress arises from an imbalance between the generation of reactive oxygen species (ROS) and the effectiveness of antioxidant defenses. Long-term oxidative stress can lead to tissue deterioration because it produces free radicals and peroxides, which

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negatively affect several organ systems, including intestinal integrity. Both endogenous and exogenous antioxidants can scavenge free radicals in the gastrointestinal tract [71]. Oxidative stress in poultry production is exacerbated by multiple factors, including high metabolic rates, intensive production systems, heat stress, and exposure to pathogens and toxins [2].

Several studies have suggested that BEO may exhibit antioxidant properties and may contribute to reducing oxidative stress in poultry, a condition associated with reduced performance, compromised immune function, and increased disease susceptibility [41,72].

Administration of microencapsulated basil oil enhanced the activity of antioxidant enzymes in the intestine of broilers by significantly increasing superoxide dismutase [73] levels, while simultaneously decreasing malondialdehyde (MDA) levels, thereby limiting lipid peroxidation [15]. In addition to its intestinal effects, BEO supplementation positively influences systemic antioxidant status, as reflected in blood biochemistry parameters by improving oxidative stress markers [38], indicating that the systemic antioxidant benefits of BEO complement its local intestinal effects, thereby supporting overall health and productivity.

Owing to its strong antioxidant capacity, BEO holds considerable promise for application throughout the poultry production chain, from farm to fork. When incorporated into poultry feed as a natural preservative, BEO can improve feed stability during storage [74]. However, the antioxidant activity of non-encapsulated BEO declines markedly with prolonged storage, limiting its practical application [16]. However, microencapsulation effectively overcomes this challenge by protecting the bioactive components of BEO, preserving its antioxidant activity under storage conditions, and ensuring consistent functional efficacy throughout feed manufacturing and extended storage periods [15,75]. Consequently, the ability of microencapsulated BEO to mitigate oxidative stress represents a significant advantage, particularly under challenging poultry production environments.

The antioxidant mechanisms of BEO involve both direct free radical scavenging by phenolic compounds and indirect enhancement of endogenous antioxidant defense systems. BEO has strong antioxidant activity, as evidenced by its capacity to scavenge different free radicals and ROS, including significant activities in 1,1-diphenyl-2-picryl-hydrazyl (DPPH) radical scavenging, superoxide anion radical scavenging, hydrogen peroxide scavenging, reducing power, and metal chelation [76]. Beyond these direct effects, BEO also modulates cellular antioxidant defenses, reducing the expression of genes associated with oxidative stress and inflammation in stimulated macrophage cells [77], while upregulating antioxidant-related genes, enhancing total antioxidant capacity, and alleviating oxidative stress in the intestine [15,78].

Moreover, these antioxidant properties are largely attributed to the rich phytochemical composition of basil. It contains a diverse range of natural compounds, including phenolic substances and polyphenols, such as total phenolics, phenolic acids, and flavonoids [79]. A strong correlation has been consistently reported between polyphenolic content and antioxidant capacity [80–82]. It has been proven that the phenolic compounds in basil extracts have potent antioxidant properties comparable to those of different synthetic antioxidants [76,83]. Extensive studies have shown that different BEO species have high antioxidant activities [40,57,84,85]. Consequently, basil represents a valuable natural source of antioxidants, offering protective benefits against oxidative damage and stress associated with inflammatory conditions [77].

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## 5. Applications of Basil Essential Oil in Poultry Production

### *5.1. Basil Essential Oil as a Natural Growth Promoter*

BEO has been extensively investigated as a phytogenic feed additive in poultry diets, with applications spanning growth promotion, health enhancement, and antibiotic replacement strategies [36,38]. Comparative studies have shown that BEO produced growth outcomes comparable to the antibiotic growth promoter avilamycin, by modulating intestinal microbiota in broilers [38].

Dietary supplementation with 1.5% basil leaf powder significantly improved the feed conversion ratio (FCR), enhanced protein metabolism, and upregulated thyroid hormones, demonstrating its efficacy as a natural growth promoter in Japanese quails [86]. While other studies found no significant improvements in growth performance with basil supplementation [87], others reported enhanced body weight gain and feed conversion ratios [88,89]. BEO at dosages of 0.3 g/kg and 0.6 g/kg, improved FCR with reduced feed intake [90], and enhanced nutrient absorption when used with other herbs [91]. Additionally, Multi-essential oil blends incorporating basil have also shown promise, demonstrating synergistic effects on production performance, meat quality, and intestinal microbiota in broiler chickens [92]. Such combinations may offer advantages over single essential oils by providing complementary antimicrobial spectra and multiple modes of action [92].

Supplements derived from plants have exhibited promising outcomes in terms of growth performance, reduction in pathogens in the digestive system, and increased villus height in the small intestine [93]. Supplementing the diets of growing quail with 0.25 g/kg of BEO enhanced growth performance [94]. Adding 0.5% sweet basil plant improved broiler performance by increasing the expression of growth hormones, which directly increased live body weight gain significantly and improved FCR [95].

In summary, BEO promotes poultry growth through multiple mechanisms that improve their health and production efficiency, as shown in Table 2. It can enhance nutrient digestibility by improving intestinal morphology, increasing villus height and surface area, and preserving intestinal integrity [15]. These improvements expand the gut absorptive capacity and support digestive enzyme activity, leading to more efficient feed utilization. BEO may play a role in enhancing nutrient utilization through antimicrobial effects, suppressing pathogenic bacteria while supporting beneficial microbiota, which reduces competition for nutrients and limits the energy diverted to immune responses [36].

The modulation of the gut microbiota is critical, as BEO can promote beneficial bacteria while inhibiting pathogens, creating a favorable intestinal environment that supports nutrient metabolism and immune system development. Furthermore, antioxidant properties of BEO protect the intestinal epithelium from oxidative damage, preserve intestinal function, and maintain nutrient absorption. Its systemic effects help mitigate chronic inflammation and oxidative stress, which can impair feed intake and growth efficiency. The integration of these mechanisms improve nutrient digestibility, microbiota modulation, and antioxidant protection, and metabolic regulation enables BEO to enhance poultry health and performance, making it a potential natural alternative to antibiotic growth promoters, as shown in Table 3.

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**Table 2.** Basil Essential oil as a natural feed additive/growth promoter in poultry diet.

| Essential oil | Form | Species | Age | Dosage | The Main Findings | Reference |
|---|---|---|---|---|---|---|
| Basil, Thyme and Sage Essential Oils | Oil | Broiler chicks (500 Cobb) | 12 days old | 0.5 g/kg feed | ✓ ↓↓ *E. coli*, *Coliforms*, and *staphylococci*<br>✓ ↑↑ *Lactobacilli* count.<br>✓ ↑↑ the antioxidant capacity<br>✓ ↑↑ Total polyphenols content in the meat | [36] |
| Basil (*Ocimum basilicum*) | Oil | Broiler chicks (Arian strain) | one day old chick | 0.2, 0.4, and 0.6 g/kg feed | ✓ ↓↓ *E. coli* number (at a higher dose).<br>✓ ↑↑ Improve carcass quality<br>✓ ↓↓ Abdominal fat content (at a lower dose). | [38] |
| Basil (*Ocimum basilicum*) | Oil | Broiler chicks (Cobb-500) | one day old chick | 10 and 20 g/kg of powder, in addition to 0.5 and 1 g/kg of oil | ✓ ↓↓ Total bacterial count<br>✓ ↓↓ *Salmonella* and *E. coli*.<br>✓ Improve carcass quality<br>✓ Improves dressing % + ↓↓ abdominal fat | [96] |
| Basil (*Ocimum basilicum*) | Oil | Broiler chicks | one-day-old female broilers (Ross 308) | 0.5 g/kg feed (free or microencapsulate) | ✓ Not affect *Lactobacillus* spp. and *E. coli*.<br>✓ Improve growth performance by improving histomorphology | [15] |
| Basil (*Ocimum basilicum*) | Oil | Two lines of quails (Coturnix coturnix), | one-day-old chicks | 0.25 and 0.5 g/kg feed | ✓ Improve growth performance<br>✓ ↑↑ BW and BWG.<br>✓ ↑↑ Feed intake and ↑↑ FCR.<br>✓ Improve carcass weight<br>✓ ↓↓↓ *E. coli* + ↑↑↑ *Lactobacillus* spp. | [94] |
| Basil leaves (*Ocimum basilicum*) | Leaf powder | Japanese quail | 9-day-old chicks | 5, 10 and 15 g/kg feed | ✓ ↓↓ Feed intake and ↑↑ FCR<br>✓ ↑↑ Thyroid hormone levels (T3 and T4)<br>✓ Improve carcass quality and quantity<br>✓ ↑↑ carcass weight + ↓↓ abdominal fat | [86] |
| Basil leaves (*Ocimum basilicum*) | Leaf powder | Japanese quail | One-day-old chicks | 3, 6, 10 g/kg feed | ↑↑ FCR | [97] |
| Basil (*Ocimum basilicum*) | Seeds | Broiler Chicks | One day-old chicks | 3 g/kg feed | ↑↑↑ body weight | [89] |

↑↑: Increased; ↑↑↑: Significantly increased; ↓↓: Decreased; ↓↓↓: Significantly decreased.

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**Table 3.** Antioxidant and immunomodulatory effects of basil essential oil in poultry.

| Essential Oil | The Form | The Dose | Species | The main effect | Reference |
| --- | --- | --- | --- | --- | --- |
| Microencapsulated basil (*Ocimum basilicum*) | Oil | 0.5 g/kg feed | Broiler chicks | ↑↑ SOD<br>↓↓ MDA | [15] |
| Basil (*Ocimum basilicum*) | Oil | 0.4 g/kg feed | Broiler chicks | ↓↓ MDA<br>↑↑ Total antioxidant capacity | [78] |
| Basil (*Ocimum sanctum*) | Leaf powder | 5 g and 10 g/kg feed | Broiler chicks (One-day-old) | ↑↑ Enhance the immune status<br>↑↑ T-cell-mediated immune response | [98] |
| Basil (*Ocimum basilicum*) | Oil | 0.5 g and 1 gm/kg feed | Broiler chicks | ↑↑ Immunological parameters:<br>↑↑ Globulin, γ-globulin, IgM, IgG, and interleukins<br>↑↑ Glutathione (GSH), glutathione peroxidase (GPX), SOD | [96] |
| Basil (*Ocimum basilicum*) | Leaf powder | 5 and 10 g/kg of feed | Broiler chicks (One-day old) | Innate Immune Response<br>↑↑ Phagocytic activity of peripheral blood monocytes<br>↑↑Serum lysozyme levels<br>↑↑ Relative weights of lymphoid organs<br>Adaptive Immune Response:<br>↑↑ antibody titers<br>↑↑ Catalase (CAT) activity & ↓↓ MDA | [99] |
| Basil (*Ocimum basilicum*) | Seed | 3 and 6 g/kg feed | Broiler chicks | ↑↑ Antibody titers against Newcastle disease virus (NDV) and infectious bronchitis (IB). | [100] |
| Basil (*Ocimum gratissimum*) | Leaf powder | 1, 5, 10, 20 g/kg feed | White Roman geese | ↑↑ Enhance humoral immune response | [101] |

↑↑: Increased; ↑↑↑: Significantly increased; ↓↓: Decreased; ↓↓↓: Significantly decreased.

*5.2. Enhancing Meat Quality with Basil Essential Oil*

Essential oils have demonstrated potential as inhibitors of foodborne pathogens, enhancers of shelf life, promoters of texture, and agents to improve organoleptic properties. Owing to their multifaceted applications, they have been suggested to have potential as food preservatives [102]. BEO, which is abundant in polyphenols [35,79], significantly enhances meat quality through various mechanisms. Its potent antioxidant properties increase the oxidative stability of meat products [36]. The inclusion of basil leaf powder in quail diets resulted in improved meat sensory traits (color/texture) and overall acceptability scores compared to the control group [86]. Additionally, supplementation with 0.2 g/kg BEO reduced abdominal fat deposition while modulating serum lipid profiles, including LDL, HDL, and total cholesterol levels [38,89]. These lipid-modulating effects suggest that BEO may improve meat fatty acid profiles by increasing stable unsaturated fatty acids while reducing oxidation-prone lipids. These results serve to prolong the shelf life and preserve the sensory characteristics of poultry products. BEO alone or in combination with rosemary essential oil significantly inhibits *Salmonella Enteritidis* growth in chicken meat and has a protective effect against meat spoilage at 4 °C standard chilling temperature to slow down microbial growth and extend the shelf life of meat [103].

Furthermore, BEO exhibits hypolipidemic effects, contributing to a reduction in abdominal fat and serum cholesterol levels [81,89,104]. These attributes highlight its effectiveness as a natural preservative capable of maintaining flavor, minimizing spoilage, and mitigating oxidative rancidity. Consequently, BEO exhibits high potential to be used as a viable, natural alternative to synthetic additives in meat preservation owing to its antibacterial activity, as it has a positive influence on reducing the count of *S. aureus* until two weeks of sausage storage [105]. Recent research has investigated the effectiveness of chicken sausages [106], nuggets [107], and fillets [108]. Oil has the ability to reduce the expression of oxidative stress-related genes and increase anti-oxidant capacity [78].

These studies investigated the effect of BEO on the expression of genes related to oxidative stress and found that the expression of genes involved in the NADPH oxidase system and nitric acid synthase [109] was reduced [15,77,110]. These genes can directly affect meat quality by affecting lipid oxidation and ROS production, which affect the organoleptic properties of meat, such as rancidity, color stability, and flavor [78,111–114]. These properties make BEO a potential candidate for food preservation and functional food production (Figure 3). Innovative approaches, such as nanoencapsulation and synergistic combinations with other preservation techniques, are being explored to enhance their efficacy in meat preservation by controlling bacterial growth and inhibiting pH increase [115–117].

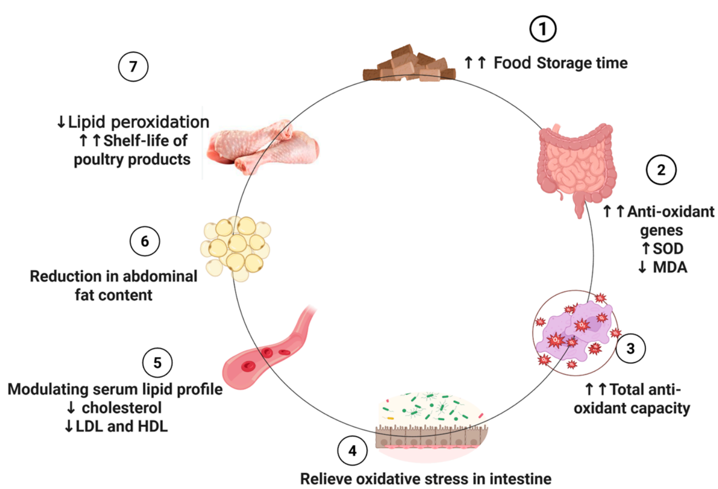


**Figure 3.** Antioxidant Role of Basil Essential Oil.

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### *5.3. Egg Sanitization*

Essential oils (EOs) have demonstrated potential as natural sanitizers for hatching eggs, presenting an alternative to formaldehyde [118]. Additionally, EOs serve as an effective, natural solution for reducing bacterial contamination of eggshells throughout storage, enhancing egg safety from farm to hatchery [119]. Research has indicated their effectiveness in reducing bacterial and fungal contamination of eggshells, thereby enhancing hatchability [120,121]. Essential oil-based sanitizing sprays can prolong the shelf life of eggs and ensure their safety for human consumption at room temperature without refrigeration [122]. In particular, BEOs have been shown to preserve egg quality and mitigate microbial growth [123]. BEO, when utilized in conjunction with cornstarch coatings, has shown promise in maintaining egg quality during storage [123]. BEOs and their main chemical components have antibacterial activity against a variety of Gram-negative and Gram-positive bacteria, mold, and yeast, which render them viable candidates for food preservation applications [124]. Recent studies have highlighted the potential of essential oil-based sanitizers to reduce bacterial contamination of the yolk sac in hatching eggs; with *Ocimum basilicum* 4.69 mg/mL effectively controls bacterial contamination on hatching eggs, enhancing hatchability and chick health without adverse effects, which offers a cost-effective, sustainable alternative to synthetic disinfectants [125].

Considerable attention has been given to the theoretical advantage of EOs in preventing resistance development; however, this advantage lacks extensive validation in commercial production. Long-term surveillance studies are needed to confirm it. Although EOs have shown promise as natural sanitizers for hatching eggs, their implementation in commercial poultry production faces challenges, including bacterial resistance risks, maintenance of optimal sanitization (time and concentration), and economic feasibility assessments [118]. Overcoming bacterial resistance by rotating various EOs is recommended, and using combinations of oils can enhance efficacy through synergistic interactions.

### *5.4. Disinfection of Poultry Housing and Improving Welfare*

In poultry farms, bioaerosols suspended in the air, including mold spores, mold fragments, and pathogenic fungi that are responsible for producing mycotoxins, pose a significant hazard. Airborne pollutants are key stressors on poultry farms. High suspended dust and gas in the air lead to the weakening of the immune system by causing inflammation in the respiratory system and allergic reactions, and facilitate the entry of pathogens such as endotoxins and microorganisms [126,127]. EOs have emerged as promising alternatives to conventional antimicrobials in poultry farming, offering potential benefits in sanitization and disease prevention. Additionally, aerosol disinfection with essential oil-based preparations or essential oil mist has been found to reduce microbial pollution in poultry houses and improve broiler growth [128,129], it is also used as an additive to the litter to reduce microbial air pollution and bacterial contamination in broiler houses. Basils are known to have strong insecticidal properties [130,131]. *Ocimum basilicum* has been suggested to exhibit insecticidal activity against *Rhyzopertha dominica*, particularly when compared to *Sitophilus oryzae*, and may contribute to the management of insect populations in stored grains [132]. EOs derived from certain Ocimum species demonstrate strong larvicidal effects against *Aedes albopictus* [133]. Accordingly, they can be effectively used as insect repellents and to control houseflies and mosquitoes because of their bioactive compounds, indicating their potential as natural larvicides. Additionally, BEO has been associated with an acaricidal effect against the poultry red mite *Dermanyssus gallinae* [134].

A clear benefit of essential oil sprays is that they can be used to disinfect poultry houses in the presence of poultry, which is considered safer than synthetic chemical products [129]. For example, adding linalool to poultry feed or bedding could address several

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challenges faced by the poultry industry. In addition to reducing or eliminating enteropathogens, linalool might also protect feed from spoilage by insects or fungi and decrease insect infestations in poultry houses [9]. Integrating EOs into poultry farming practices, including sanitizing poultry houses, poultry, and hatching eggs, can contribute to the production of microbiologically safe eggs and improve overall farm hygiene [30]. However, further research is needed to optimize dosages and evaluate economic feasibility [130]. Research on the use of EOs, particularly BEO, for aerosol disinfection is limited, and their potential impact on reducing mycotoxins, a significant issue in poultry farming, remains uncertain. Overall, BEO offers a multifaceted approach to enhance poultry house sanitization and bird health.

## 6. Microencapsulation of Basil Essential Oil and Its Industrial Applications

EOs are susceptible to degradation when exposed to heat, acids, oxygen, or light. Microencapsulation is a technological approach for safeguarding the active components during processing and storage [135]. This process produces capsules by capturing active compounds within one or more types of wall material to form small capsules (Table 4, Figure 4). The core material is protected from chemical and physical reactions, thus preserving its biological and physicochemical properties [117]. In the poultry sector, encapsulation technology can enhance the stability, bioavailability, and controlled release of active ingredients, thereby increasing their effectiveness as feed additives [15]. In food preservation, encapsulating BEO may increase its potential as a natural preservative for meat products by improving their safety (reduced pathogens/spoilage), quality (enhanced pH/lipid stability), and sensory acceptability of meat products during storage [136]. Chitosan films loaded with microencapsulated BEO show great potential as active preservative packaging, effectively extending shelf life by inhibiting bacterial growth and maintaining an optimum pH level [117]. However, there is limited research on the use of microencapsulated BEO in processed and refrigerated chicken products.

BEO nanocapsules can enhance the antioxidant and antibacterial activities and encapsulation efficiency under various storage conditions. This enhancement aids in minimizing issues, such as food spoilage and foodborne diseases, which pose significant risks to human health; however, their safety in food production requires careful evaluation. Regulatory frameworks are still evolving, necessitating robust safety data for approval and consumer acceptance. Additionally. Comprehensive cost–benefit analyses are therefore essential to guide practical implementation (Figure 4).

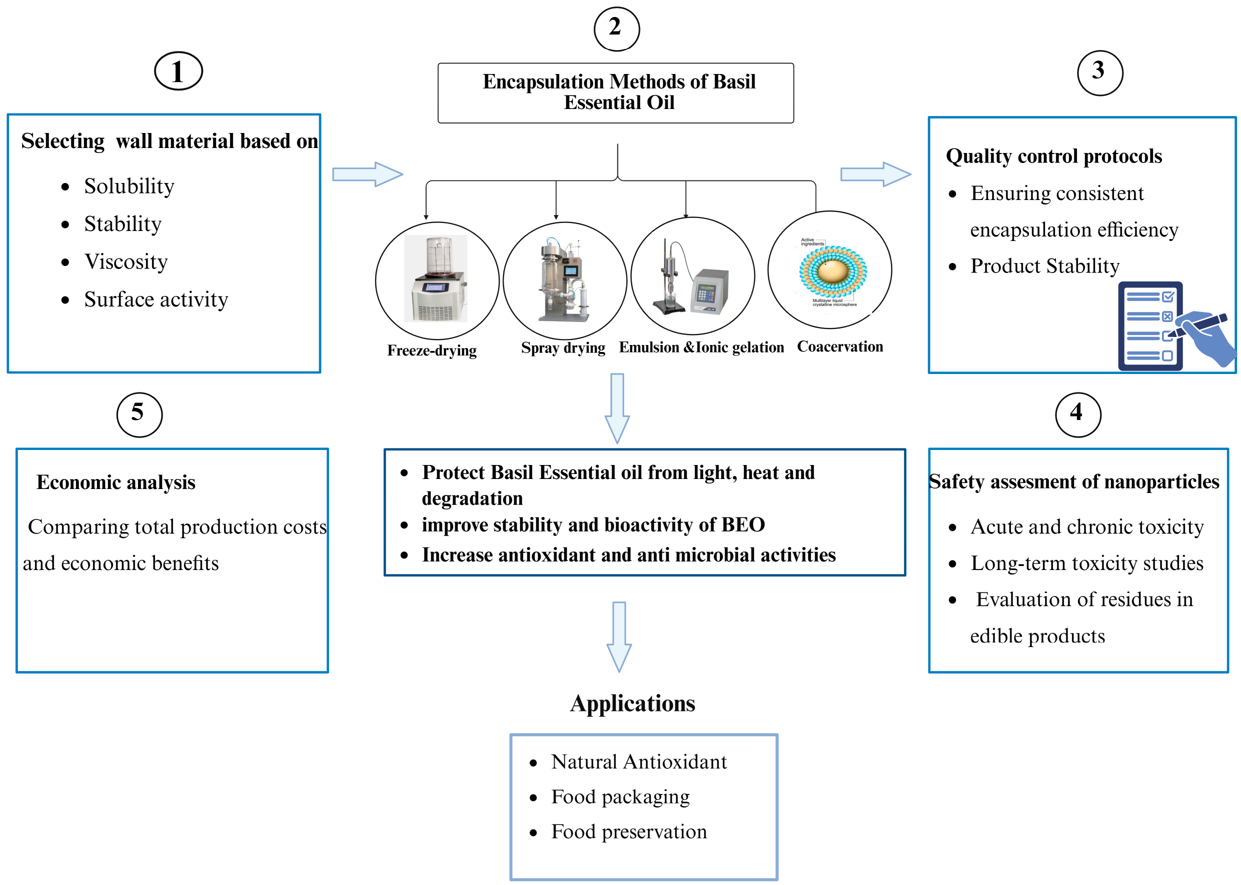


**Figure 4.** Encapsulation Methods, Applications and Limitations of Basil Essential Oil.

**Table 4.** Encapsulation strategies and applications of basil essential oil.

| Essential Oil | Wall Materials | Encapsulation Method | Outcomes | Applications | Reference |
|---|---|---|---|---|---|
| Basil essential oil | Native gums (locust seed gum, lentil protein, lentil protein/locust seed gum) | Freeze-drying Nano encapsulation | ↑↑ antioxidant activity ↓↓ the oxidation process | Natural antioxidant | [137] |
| Basil essential oil | Chitosan nanoparticles | Emulsion and ionic gelation | Strong antibacterial against E. coli and S. aureus | Food packaging | [138] |
| Holy basil essential oil | Gelatin | Simple coacervation | Protection from physical and chemical degradation caused by oxygen, light, moisture, and heat. | Extended shelf life (60 °C for 49 days) | [139] |
| Basil essential oil | Sodium alginate, Sodium caseinate, maltodextrin | Spray drying | Improve encapsulation efficiency | Extended shelf life | [140] |
| Basil essential oil | Pectin/casein biopolymers | Complex coacervation | ↑↑ Encapsulation Efficiency (93.10%) ↑↑↑ Thermal stability | Food preservation Food processing | [141] |
| Basil Essential Oil | Alginic acid sodium salt | Vibration technology | ↑↑ Encapsulation Efficiency (87%) | Food packaging | [117] |

| | | | | | |
|---|---|---|---|---|---|
| Basil Essential Oil | Maltodextrin/gum arabic (1:1) | Freeze-drying | ↓↓↓ bacterial counts, +improved sensory properties | Food preservation | [136] |
| Basil Essential Oil | Gum with dextrin | Spray drying Oil in water emulsion | ↑↑↑ Encapsulation Efficiency (96.46–97.22%) Antibacterial activity | Antibacterial activity (60 °C storage condition) | [142] |

↑↑: Increased; ↑↑↑: Highly increased; ↓↓: Decreased; ↓↓↓: Significantly decreased.

## 7. Conclusions and Future Perspectives

Despite its beneficial bioactive properties, the direct application of free basil essential oil (BEO) in poultry feed presents several challenges. BEO is highly volatile and prone to oxidation, leading to rapid degradation and loss of efficacy when exposed to air, light, or high temperatures during feed processing and storage. This instability significantly reduces its efficacy as a feed additive. In addition, BEO exhibits low water solubility and poor bioavailability, which limit its absorption in the gastrointestinal tract and compromise its biological effectiveness.

Dosage optimization remains a critical concern; low inclusion levels may be insufficient to elicit biological responses, while higher doses can induce toxicity, reduce palatability, and negatively affect growth performance and feed intake. Moreover, interactions between BEO and other feed components may influence its stability and efficacy, yet these interactions are not well characterized. These limitations highlight the need for advanced delivery systems, such as nanoencapsulation, to enhance BEO's stability, solubility, and controlled release in poultry nutrition. Although nanoformulation technologies can address stability challenges, the associated additional costs may increase overall product costs; however, enhanced efficacy may result in more favorable cost–benefit ratios. Moreover, the absence of robust economic feasibility assessments constitutes a significant limitation, restricting large-scale application and commercial implementation of these interventions in broiler production systems.

Future research on BEO should prioritize (1) long-term studies to elucidate the underlying molecular pathways and (2) large-scale field validation under commercial production conditions. Additional efforts are needed for (3) dosage optimization and (4) comprehensive economic analyses. Further directions include (5) integrating BEO into stress-mitigation strategies and (6) exploring in ovo injection as a tool for early-life programming. Research should also address (7) the effects of BEO on egg production and (8) the development of management programs that combine BEO with other natural additives, probiotics, and prebiotics to achieve synergistic benefits beyond those attainable with individual interventions. Moreover, BEO may be investigated for (9) enhancing immune responses during vaccination programs. Finally, (10) rigorous head-to-head comparisons, well-designed studies directly comparing BEO with standard ionophores under commercial challenge conditions, with comprehensive economic analysis.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture16080869/s1, Table S1: The variations in the chemical composition of basil essential oils

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**Conflicts of Interest:** The authors declare no conflicts of interest.

## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| BEO | Basil Essential Oil |
| MP | Membrane Potential |
| AKP | Alkaline Phosphatase |
| ROS | Reactive Oxygen Species |
| SOD | Superoxide Dismutase |
| MDA | Malondialdehyde |
| DPPH | 1,1-diphenyl-2-picryl-hydrazyl |
| GSH | Glutathione |
| GPX | Glutathione Peroxidase |

## References

1. Aminullah, N.; Mostamand, A.; Zahir, A.; Mahaq, O.; Azizi, M.N. Phytogenic feed additives as alternatives to antibiotics in poultry production: A review. *Vet. World* **2025**, *18*, 141–154. https://doi.org/10.14202/vetworld.2025.141-154.
2. Krauze, M. Phytobiotics, a natural growth promoter for poultry. In *Advanced Studies in the 21st Century Animal Nutrition*; IntechOpen: London, UK, 2021; Volume 8. https://doi.org/10.5772/INTECHOPEN.99030.
3. Abd El-Hack, M.E.; El-Saadony, M.T.; Saad, A.M.; Salem, H.M.; Ashry, N.M.; Ghanima, M.M.A.; Shukry, M.; Swelum, A.A.; Taha, A.E.; El-Tahan, A.M. Essential oils and their nanoemulsions as green alternatives to antibiotics in poultry nutrition: A comprehensive review. *Poult. Sci.* **2022**, *101*, 101584. https://doi.org/10.1016/j.psj.2021.101584.
4. Mnisi, C.M.; Mlambo, V.; Gila, A.; Matabane, A.N.; Mthiyane, D.M.; Kumanda, C.; Manyeula, F.; Gajana, C.S. Antioxidant and antimicrobial properties of selected phytogenics for sustainable poultry production. *Appl. Sci.* **2022**, *13*, 99. https://doi.org/10.3390/app13010099.
5. Abdelli, N.; Solà-Oriol, D.; Pérez, J.F. Phytogenic feed additives in poultry: Achievements, prospective and challenges. *Animals* **2021**, *11*, 3471. https://doi.org/10.3390/ani11123471.
6. Iskandar, K.; Ahmed, N.; Paudyal, N.; Ruiz Alvarez, M.-J.; Balasubramani, S.P.; Saadeh, D.; Ullah Baig, S.; Sami, H.; Hammoudi Halat, D.; Pavlović, N. Essential Oils as antimicrobial agents against WHO Priority bacterial pathogens: A strategic review of in vitro clinical efficacy, innovations and research gaps. *Antibiotics* **2025**, *14*, 1250. https://doi.org/10.3390/antibiotics14121250.
7. Falleh, H.; Jemaa, M.B.; Saada, M.; Ksouri, R. Essential oils: A promising eco-friendly food preservative. *Food Chem.* **2020**, *330*, 127268. https://doi.org/10.1016/j.foodchem.2020.127268.
8. Pan, J.; Zhu, Y.; Abdel-Samie, M.A.; Li, C.; Cui, H.; Lin, L. Biological properties of essential oil emphasized on the feasibility as antibiotic substitute in feedstuff. *Grain Oil Sci. Technol.* **2023**, *6*, 10–23.
9. Xiao, G.; Zheng, L.; Yan, X.; Gong, L.; Yang, Y.; Qi, Q.; Zhang, X.; Zhang, H. Effects of dietary essential oils supplementation on egg quality, biochemical parameters, and gut microbiota of late-laying hens. *Animals* **2022**, *12*, 2561. https://doi.org/10.3390/ani12192561.
10. Krishan, G.; Narang, A. Use of essential oils in poultry nutrition: A new approach. *J. Adv. Vet. Anim. Res.* **2014**, *1*, 156–162. https://doi.org/10.5455/javar.2014.a36.

11. Beier, R.C.; Byrd, J.A., II; Kubena, L.F.; Hume, M.E.; McReynolds, J.L.; Anderson, R.C.; Nisbet, D.J. Evaluation of linalool, a natural antimicrobial and insecticidal essential oil from basil: Effects on poultry. *Poult. Sci.* **2014**, *93*, 267–272. https://doi.org/10.3382/ps.2013-03254.
12. Oliveira, G.d.S.; McManus, C.; Sousa, H.A.d.F.; Santos, P.H.G.d.S.; Dos Santos, V.M. A mini-review of the main effects of essential oils from Citrus aurantifolia, Ocimum basilicum, and *Allium sativum* as safe antimicrobial activity in poultry. *Animals* **2024**, *14*, 382. https://doi.org/10.3390/ani14030382.
13. Rajendran, D.; Ezhuthupurakkal, P.B.; Lakshman, R.; Gowda, N.K.S.; Manimaran, A.; Rao, S.B. Application of encapsulated nano materials as feed additive in livestock and poultry: A review. *Vet. Res. Commun.* **2022**, *46*, 315–328. https://doi.org/10.1007/s11259-022-09895-7.
14. Patra, J.K.; Das, G.; Fraceto, L.F.; Campos, E.V.R.; Rodriguez-Torres, M.d.P.; Acosta-Torres, L.S.; Diaz-Torres, L.A.; Grillo, R.; Swamy, M.K.; Sharma, S. Nano based drug delivery systems: Recent developments and future prospects. *J. Nanobiotechnol.* **2018**, *16*, 71. https://doi.org/10.1186/s12951-018-0392-8.
15. Thuekeaw, S.; Angkanaporn, K.; Nuengjamnong, C. Microencapsulated basil oil (*Ocimum basilicum* Linn.) enhances growth performance, intestinal morphology, and antioxidant capacity of broiler chickens in the tropics. *Anim. Biosci.* **2022**, *35*, 752. https://doi.org/10.5713/ab.21.0299.
16. Thuekeaw, S. Microencapsulation of Basil Oil and Its Effect on Replacement of Antibiotic Growth Promoter, Antioxidant Status and Gut Functions of Broilers. Ph.D. Thesis, Chulalongkorn University, Bangkok, Thailand, 2022.
17. Sakkas, H.; Papadopoulou, C. Antimicrobial activity of basil, oregano, and thyme essential oils. *J. Microbiol. Biotechnol* **2017**, *27*, 429–438. https://doi.org/10.4014/jmb.1608.08024.
18. Beatovic, D.; Krstic-Milosevic, D.; Trifunovic, S.; Siljegovic, J.; Glamoclija, J.; Ristic, M.; Jelacic, S. Chemical composition, antioxidant and antimicrobial activities of the essential oils of twelve *Ocimum basilicum* L. cultivars grown in Serbia. *Rec. Nat. Prod.* **2015**, *9*, 62.
19. Lambert, R.; Skandamis, P.N.; Coote, P.J.; Nychas, G.J. A study of the minimum inhibitory concentration and mode of action of oregano essential oil, thymol and carvacrol. *J. Appl. Microbiol.* **2001**, *91*, 453–462. https://doi.org/10.1046/j.1365-2672.2001.01428.x.
20. Ru, Y.; Zhu, Y.; Wang, X.; Dong, Q.; Ma, Y. Edible antimicrobial yeast-based coating with basil essential oil for enhanced food safety. *Innov. Food Sci. Emerg. Technol.* **2024**, *93*, 103612. https://doi.org/10.1016/j.ifset.2024.103612.
21. Ch, M.; Naz, S.; Sharif, A.; Akram, M.; Saeed, M. Biological and pharmacological properties of the sweet basil (*Ocimum basilicum*). *Br. J. Pharm. Res.* **2015**, *7*, 330–339. https://doi.org/10.9734/bjpr/2015/16505.
22. Zheljazkov, V.D.; Callahan, A.; Cantrell, C.L. Yield and oil composition of 38 basil (*Ocimum basilicum* L.) accessions grown in Mississippi. *J. Agric. Food Chem.* **2008**, *56*, 241–245. https://doi.org/10.1021/jf072447y.
23. Chalchat, J.-C.; Özcan, M.M. Comparative essential oil composition of flowers, leavesand stems of basil (*Ocimum basilicum* L.) used as herb. *Food Chem.* **2008**, *110*, 501–503. https://doi.org/10.1016/j.foodchem.2008.02.018.
24. Elgndi, M.A.; Filip, S.; Pavlić, B.; Vladić, J.; Stanojković, T.; Žižak, Ž.; Zeković, Z. Antioxidative and cytotoxic activity of essential oils and extracts of *Satureja montana* L., *Coriandrum sativum* L. and *Ocimum basilicum* L. obtained by supercritical fluid extraction. *J. Supercrit. Fluids* **2017**, *128*, 128–137. https://doi.org/10.1016/j.supflu.2017.05.025.
25. Kathirvel, P.; Ravi, S. Chemical composition of the essential oil from basil (*Ocimum basilicum* Linn.) and its in vitro cytotoxicity against HeLa and HEp-2 human cancer cell lines and NIH 3T3 mouse embryonic fibroblasts. *Nat. Prod. Res.* **2012**, *26*, 1112–1118. https://doi.org/10.1080/14786419.2010.545357.
26. Branca, F.; Treccarichi, S.; Ruberto, G.; Renda, A.; Argento, S. Comprehensive Morphometric and Biochemical Characterization of Seven Basil (*Ocimum basilicum* L.) Genotypes: Focus on Light Use Efficiency. *Agronomy* **2024**, *14*, 224. https://doi.org/10.3390/agronomy14010224.
27. Majdi, C.; Pereira, C.; Dias, M.I.; Calhelha, R.C.; Alves, M.J.; Rhourri-Frih, B.; Charrouf, Z.; Barros, L.; Amaral, J.S.; Ferreira, I.C. Phytochemical characterization and bioactive properties of cinnamon basil (*Ocimum basilicum* cv. 'Cinnamon') and lemon basil (*Ocimum* × *citriodorum*). *Antioxidants* **2020**, *9*, 369. https://doi.org/10.3390/antiox9050369.
28. Bajomo, E.M.; Aing, M.S.; Ford, L.S.; Niemeyer, E.D. Chemotyping of commercially available basil (*Ocimum basilicum* L.) varieties: Cultivar and morphotype influence phenolic acid composition and antioxidant properties. *NFS J.* **2022**, *26*, 1–9. https://doi.org/10.1016/j.nfs.2022.01.001.
29. Avetisyan, A.; Markosian, A.; Petrosyan, M.; Sahakyan, N.; Babayan, A.; Aloyan, S.; Trchounian, A. Chemical composition and some biological activities of the essential oils from basil Ocimum different cultivars. *BMC Complement. Altern. Med.* **2017**, *17*, 60.
30. Telci, I.; Bayram, E.; Yılmaz, G.; Avcı, B. Variability in essential oil composition of Turkish basils (*Ocimum basilicum* L.). *Biochem. Syst. Ecol.* **2006**, *34*, 489–497. https://doi.org/10.1016/j.bse.2006.01.009.

31. da Silva, W.M.F.; Kringel, D.H.; de Souza, E.J.D.; da Rosa Zavareze, E.; Dias, A.R.G. Basil essential oil: Methods of extraction, chemical composition, biological activities, and food applications. *Food Bioprocess Technol.* **2022**, *15*, 1–27.
32. Lawrence, B. A further examination of the variation of *Ocimum basilicum* L. *Dev. Food Sci.* **1988**, *18*, 161–170.
33. Dai, Z.-L.; Wu, G.; Zhu, W.-Y. Amino acid metabolism in intestinal bacteria: Links between gut ecology and host health. *Front. Biosci.* **2011**, *16*, 1768–1786. https://doi.org/10.2741/3820.
34. Zhao, H.; Ren, S.; Yang, H.; Tang, S.; Guo, C.; Liu, M.; Tao, Q.; Ming, T.; Xu, H. Peppermint essential oil: Its phytochemistry, biological activity, pharmacological effect and application. *Biomed. Pharmacother.* **2022**, *154*, 113559.
35. Yaldiz, G.; Çamlıca, M.; Ozen, F. Biological value and chemical components of essential oils of sweet basil (*Ocimum basilicum* L.) grown with organic fertilization sources. *J. Sci. Food Agric.* **2018**, *99*, 2005–2013. https://doi.org/10.1002/jsfa.9468.
36. Vlaicu, P.A.; Untea, A.E.; Panaite, T.D.; Saracila, M.; Turcu, R.P.; Dumitru, M. Effect of basil, thyme and sage essential oils as phytogenic feed additives on production performances, meat quality and intestinal microbiota in broiler chickens. *Agriculture* **2023**, *13*, 874. https://doi.org/10.3390/agriculture13040874.
37. Oliveira, G.d.S.; McManus, C.; Vale, I.R.R.; dos Santos, V.M. Obtaining Microbiologically Safe Hatching Eggs from Hatcheries: Using Essential Oils for Integrated Sanitization Strategies in Hatching Eggs, Poultry Houses and Poultry. *Pathogens* **2024**, *13*, 260. https://doi.org/10.3390/pathogens13030260.
38. Riyazi, S.; Ebrahimnezhad, Y.; Hosseini, S.; Meimandipour, A.; Ghorbani, A. Comparison of the effects of basil (*Ocimum basilicum*) essential oil, avilamycin and protexin on broiler performance, blood biochemistry and carcass characteristics. *Arch. Anim. Breed.* **2015**, *58*, 425–432. https://doi.org/10.5194/aab-58-425-2015.
39. Riyazi, S.R.; Ebrahimnezhad, Y.; Hosseini, S.A.; Meimandipour, A.; Ghorbani, A. Effects of antibiotic growth promoter, probiotic and basil essential oil supplementation on the intestinal microflora of broiler chickens. *J. Biosci. Biotechnol.* **2015**, *4*, 185.
40. Yibeltal, G.; Yusuf, Z.; Desta, M. Physicochemical properties, antioxidant and antimicrobial activities of Ethiopian sweet basil (*Ocimum basilicum* L.) leaf and flower oil extracts. *Recent Adv. Anti-Infect. Drug Discov.* **2022**, *17*, 131–138.
41. Stanojevic, L.P.; Marjanovic-Balaban, Z.R.; Kalaba, V.D.; Stanojevic, J.S.; Cvetkovic, D.J.; Cakic, M.D. Chemical composition, antioxidant and antimicrobial activity of basil (*Ocimum basilicum* L.) essential oil. *J. Essent. Oil Bear. Plants* **2017**, *20*, 1557–1569. https://doi.org/10.1080/0972060X.2017.1401963.
42. Rattanachaikunsopon, P.; Phumkhachorn, P. Antimicrobial activity of basil (*Ocimum basilicum*) oil against Salmonella enteritidis in vitro and in food. *Biosci. Biotechnol. Biochem.* **2010**, *74*, 1200–1204. https://doi.org/10.1271/bbb.90939.
43. Castro-Vargas, R.E.; Herrera-Sánchez, M.P.; Rodríguez-Hernández, R.; Rondón-Barragán, I.S. Antibiotic resistance in Salmonella spp. isolated from poultry: A global overview. *Vet. World* **2020**, *13*, 2070. https://doi.org/10.14202/vetworld.2020.2070-2084.
44. Sorour, H.K.; Hosny, R.A.; Elmasry, D.M. Effect of peppermint oil and its microemulsion on necrotic enteritis in broiler chickens. *Vet. World* **2021**, *14*, 483. https://doi.org/10.14202/vetworld.2021.483-491.
45. Jin, X.; Huang, G.; Luo, Z.; Hu, Y.; Liu, D. Oregano (*Origanum vulgare* L.) essential oil feed supplement protected broilers chickens against Clostridium perfringens induced necrotic enteritis. *Agriculture* **2021**, *12*, 18. https://doi.org/10.3390/agriculture12010018.
46. Aqeel, M.; Mirani, A.H.; Khoso, P.A.; Sahito, J.K.; Bhutto, A.L.; Leghari, R.A.; Rahimoon, M.M.; Ali, K.; Ali, N. A review on the study of immunomodulators and herbal remedies: A natural approach to treating necrotic enteritis. *Pure Appl. Biol.* **2024**, *13*, 275–302. https://doi.org/10.19045/bspab.2024.130026.
47. Geng, T.; Peng, X.; Wu, L.; Shen, B.; Fang, R.; Zhao, J.; Zhou, Y. Anticoccidial activity of essential oils containing eugenol against Eimeria tenella in broiler chickens. *Anim. Dis.* **2024**, *4*, 12. https://doi.org/10.1186/s44149-024-00116-z.
48. Lee, J.; Ko, H.; Goo, D.; Sharma, M.K.; Liu, G.; Shi, H.; Paneru, D.; Choppa, V.S.R.; Maertens, B.; Sol, C. Effects of dietary supplementation with a polyherbal based product on sporozoites viability and on growth performance, lesion score, gut permeability, oocyst shedding count, tight junction, pro-inflammatory cytokine, and antioxidant enzyme in broiler chickens challenged with *Eimeria* spp. *Poult. Sci.* **2025**, *104*, 105002. https://doi.org/10.1016/j.psj.2025.105002.
49. Park, I.; Nam, H.; Wickramasuriya, S.S.; Lee, Y.; Wall, E.H.; Ravichandran, S.; Lillehoj, H.S. Host-mediated beneficial effects of phytochemicals for prevention of avian coccidiosis. *Front. Immunol.* **2023**, *14*, 1145367. https://doi.org/10.3389/fimmu.2023.1145367.
50. Onwurah, F.; Ojewola, G.; Akomas, S. Effect of basil (*Ocimum basilicum* L.) on coccidial infection in broiler chicks. *Acad. Res. Int.* **2011**, *1*, 438.
51. Felici, M.; Tugnoli, B.; Ghiselli, F.; Baldo, D.; Ratti, C.; Piva, A.; Grilli, E. Investigating the effects of essential oils and pure botanical compounds against Eimeria tenella in vitro. *Poult. Sci.* **2023**, *102*, 102898. https://doi.org/10.1016/j.psj.2023.102898.

52. Küçükyilmaz, K.; Bozkurt, M.; Selek, N.; Güven, E.; Eren, H.; Atasever, A.; Bintaş, E.; Çatlı, A.U.; Çınar, M. Effects of vaccination against coccidiosis, with and without a specific herbal essential oil blend, on performance, oocyst excretion and serum IBD titers of broilers reared on litter. *Ital. J. Anim. Sci.* **2012**, *11*, e1. https://doi.org/10.4081/ijas.2012.e1.
53. Sun, J.; Bao, W.; Han, Y.; Zhang, R.; Zhou, Z. Effect of Substituting Polyether Ionophore Anticoccidial Drugs With 1, 8-Cineole for the Control of Eimeria Infections in Broilers. *Vet. Med. Sci.* **2025**, *11*, e70341. https://doi.org/10.1002/vms3.70341.
54. Matte, E.H.C.; Luciano, F.B.; Evangelista, A.G. Essential oils and essential oil compounds in animal production as antimicrobials and anthelmintics: An updated review. *Anim. Health Res. Rev.* **2023**, *24*, 1–11. https://doi.org/10.1017/S1466252322000093.
55. Viollon, C.; Chaumont, J.-P. Antifungal properties of essential oils and their main components upon Cryptococcus neoformans. *Mycopathologia* **1994**, *128*, 151–153.
56. Ajmal, M.; Nijabat, A.; Sajjad, I.; Haider, S.Z.; Bedale, W.; Yu, J.-H.; Shah, M.A.; Ukozehasi, C.; Alwaili, M.A.; Elkelish, A. Evaluation of basil essential oils for antifungal and anti-aflatoxigenic activity against Aspergillus flavus. *Sci. Rep.* **2025**, *15*, 6168. https://doi.org/10.1038/s41598-025-87397-7.
57. Mkaddem Mounira, G.; Ahlem, Z.; Abdallah Mariem, B.; Romdhane, M.; Okla, M.K.; Al-Hashimi, A.; Alwase, Y.A.; Madnay, M.M.; AbdElgayed, G.; Asard, H. Essential oil composition and antioxidant and antifungal activities of two varieties of *Ocimum basilicum* L. (Lamiaceae) at two phenological stages. *Agronomy* **2022**, *12*, 825. https://doi.org/10.3390/agronomy12040825.
58. Elzaiat, M.A.; Mandour, A.S.; Youssef, M.A.; Wafa, H.A.; Aljahdali, S.M.; Shakak, A.O.; Al Husnain, L.; Alqahtani, M.A.; Alghamdi, M.A.; Abuzaid, A.O. Biochemical and Molecular Characterization of Five Basil Cultivars Extract for Enhancing the Antioxidant, Antiviral, Anticancer, Antibacterial and Antifungal Activities. *Pak. Vet. J.* **2024**, *44*, 1105–1119. https://doi.org/10.29261/pakvetj/2024.279.
59. Maurya, A.; Prasad, J.; Das, S.; Dwivedy, A.K. Essential oils and their application in food safety. *Front. Sustain. Food Syst.* **2021**, *5*, 653420. https://doi.org/10.3389/fsufs.2021.653420.
60. Opalchenova, G.; Obreshkova, D. Comparative studies on the activity of basil—An essential oil from *Ocimum basilicum* L.—Against multidrug resistant clinical isolates of the genera Staphylococcus, Enterococcus and Pseudomonas by using different test methods. *J. Microbiol. Methods* **2003**, *54*, 105–110. https://doi.org/10.1016/S0167-7012(03)00012-5.
61. An, Q.; Ren, J.-N.; Li, X.; Fan, G.; Qu, S.-S.; Song, Y.; Li, Y.; Pan, S.-Y. Recent updates on bioactive properties of linalool. *Food Funct.* **2021**, *12*, 10370–10389.
62. Koutsoudaki, C.; Krsek, M.; Rodger, A. Chemical composition and antibacterial activity of the essential oil and the gum of Pistacia lentiscus Var. chia. *J. Agric. Food Chem.* **2005**, *53*, 7681–7685.
63. Baylan, M.; Akpınar, G.; Canogullari, S.; Ayasan, T. The effects of using garlic extract for quail hatching egg disinfection on hatching results and performance. *Braz. J. Poult. Sci.* **2018**, *20*, 343–350.
64. Liu, X.; Cai, J.; Chen, H.; Zhong, Q.; Hou, Y.; Chen, W.; Chen, W. Antibacterial activity and mechanism of linalool against Pseudomonas aeruginosa. *Microb. Pathog.* **2020**, *141*, 103980. https://doi.org/10.1016/j.micpath.2020.103980.
65. Guo, F.; Liang, Q.; Zhang, M.; Chen, W.; Chen, H.; Yun, Y.; Zhong, Q.; Chen, W. Antibacterial activity and mechanism of linalool against Shewanella putrefaciens. *Molecules* **2021**, *26*, 245. https://doi.org/10.3390/molecules26010245.
66. Wu, K.-G.; Zhao, X.-X.; Duan, X.-J.; Chai, X.-H.; Yu, H.-P.; Liu, X.-L.; Fan, Y. Antibacterial activity and mechanism of action of vapor-phase linalool. *J. Food Sci.* **2020**, *41*, 61–67. https://doi.org/10.7506/spkx1002-6630-20181130-365.
67. Modjinou, T.; Versace, D.-L.; Abbad-Andallousi, S.; Bousserrhine, N.; Babinot, J.; Langlois, V.; Renard, E. Antibacterial Networks Based on Isosorbide and Linalool by Photoinitiated Process. *ACS Sustain. Chem. Eng.* **2015**, *3*, 1094–1100. https://doi.org/10.1021/acssuschemeng.5b00018.
68. Herman, A.; Tambor, K.; Herman, A. Linalool affects the antimicrobial efficacy of essential oils. *Curr. Microbiol.* **2016**, *72*, 165–172. https://doi.org/10.1007/s00284-015-0933-4.
69. He, R.; Zhang, Z.; Xu, L.; Chen, W.; Zhang, M.; Zhong, Q.; Chen, H.; Chen, W. Antibacterial mechanism of linalool emulsion against Pseudomonas aeruginosa and its application to cold fresh beef. *World J. Microbiol. Biotechnol.* **2022**, *38*, 56. https://doi.org/10.1007/s11274-022-03233-4.
70. Zhakipbekov, K.; Turgumbayeva, A.; Akhelova, S.; Bekmuratova, K.; Blinova, O.; Utegenova, G.; Shertaeva, K.; Sadykov, N.; Tastambek, K.; Saginbazarova, A. Antimicrobial and other pharmacological properties of *Ocimum basilicum*, *Lamiaceae*. *Molecules* **2024**, *29*, 388. https://doi.org/10.3390/molecules29020388.
71. Brown, K.; Molcan, E.; Rajendiran, E.; Nusrat, A.; Baker, J.; Ruscheinsky, S.; Gibson, D.L. Free radicals and gastrointestinal disorders. In *Systems Biology of Free Radicals and Antioxidants*; Springer: Berlin/Heidelberg, Germany, 2014; pp. 1691–1727.
72. Shafique, M.; Khan, S.J.; Khan, N.H. Study of antioxidant and antimicrobial activity of sweet basil (*Ocimum basilicum*) essential oil. *Pharmacologyonline* **2011**, *1*, 105–111.

73. Villareal, M.O.; Ikeya, A.; Sasaki, K.; Arfa, A.B.; Neffati, M.; Isoda, H. Anti-stress and neuronal cell differentiation induction effects of *Rosmarinus officinalis* L. essential oil. *BMC Complement. Altern. Med.* **2017**, *17*, 549.
74. Sharifi-Rad, J.; Adetunji, C.O.; Olaniyan, O.T.; Ojo, S.K.; Samuel, M.O.; Temitayo, B.T.; Roli, O.I.; Nimota, O.O.; Oluwabunmi, B.T.; Adetunji, J.B. Antimicrobial, antioxidant and other pharmacological activities of Ocimum Species: Potential to be used as food preservatives and functional ingredients. *Food Rev. Int.* **2023**, *39*, 1547–1577. https://doi.org/10.1080/87559129.2021.1934693.
75. Ngamakeue, N.; Chitprasert, P. Encapsulation of holy basil essential oil in gelatin: Effects of palmitic acid in carboxymethyl cellulose emulsion coating on antioxidant and antimicrobial activities. *Food Bioprocess Technol.* **2016**, *9*, 1735–1745. https://doi.org/10.1007/s11947-016-1756-4.
76. Gülçin, I.; Elmastaş, M.; Aboul-Enein, H.Y. Determination of antioxidant and radical scavenging activity of Basil (*Ocimum basilicum* L. Family Lamiaceae) assayed by different methodologies. *Phytother. Res.* **2007**, *21*, 354–361. https://doi.org/10.1002/ptr.2069.
77. Kavoosi, G.; Amirghofran, Z. Chemical composition, radical scavenging and anti-oxidant capacity of *Ocimum basilicum* essential oil. *J. Essent. Oil Res.* **2017**, *29*, 189–199. https://doi.org/10.1080/10412905.2016.1213667.
78. Elmeligy, E.H.; Attallah, S.T.; Sallam, E.A.; Mohammed, L.S. Impact of Yucca extract and basil oil supplementation on carcass characteristics, quality of meat, and the cecal microbiota in broiler chickens. *J. Adv. Vet. Res.* **2025**, *15*, 20–27.
79. Prinsi, B.; Morgutti, S.; Negrini, N.; Faoro, F.; Espen, L. Insight into Composition of Bioactive Phenolic Compounds in Leaves and Flowers of Green and Purple Basil. *Plants* **2019**, *9*, 22.
80. Złotek, U.; Mikulska, S.; Nagajek, M.; Świeca, M. The effect of different solvents and number of extraction steps on the polyphenol content and antioxidant capacity of basil leaves (*Ocimum basilicum* L.) extracts. *Saudi J. Biol. Sci.* **2016**, *23*, 628–633. https://doi.org/10.1016/j.sjbs.2015.08.002.
81. Gökçe, Y.; Kanmaz, H.; Er, B.; Sahin, K.; Hayaloglu, A. Influence of purple basil (*Ocimum basilicum* L.) extract and essential oil on hyperlipidemia and oxidative stress in rats fed high-cholesterol diet. *Food Biosci.* **2021**, *43*, 101228. https://doi.org/10.1016/j.fbio.2021.101228.
82. Nguyen, V.; Nguyen, N.; Thi, N.; Thi, C.; Truc, T.; Nghi, P. Studies on chemical, polyphenol content, flavonoid content, and antioxidant activity of sweet basil leaves (*Ocimum basilicum* L.). In Proceedings of the IOP Conference Series: Materials Science and Engineering, Suzhou, China, 17–19 March 2021; p. 012083.
83. Rice-Evans, C.A.; Miller, N.J.; Paganga, G. Structure-antioxidant activity relationships of flavonoids and phenolic acids. *Free Radic. Biol. Med.* **1996**, *20*, 933–956. https://doi.org/10.1016/0891-5849(95)02227-9.
84. Güez, C.M.; Souza, R.O.d.; Fischer, P.; Leão, M.F.d.M.; Duarte, J.A.; Boligon, A.A.; Athayde, M.L.; Zuravski, L.; Oliveira, L.F.S.d.; Machado, M.M. Evaluation of basil extract (*Ocimum basilicum* L.) on oxidative, anti-genotoxic and anti-inflammatory effects in human leukocytes cell cultures exposed to challenging agents. *Braz. J. Pharm. Sci.* **2017**, *53*, e15098. https://doi.org/10.1590/s2175-97902017000115098.
85. Hanif, M.A.; Al-Maskari, M.Y.; Al-Maskari, A.; Al-Shukaili, A.; Al-Maskari, A.Y.; Al-Sabahi, J.N. Essential oil composition, antimicrobial and antioxidant activities of unexplored Omani basil. *J. Med. Plants Res.* **2011**, *5*, 751–757.
86. Aly, M.M.; Bahnas, M.S.; Soliman, S.I. Effect of basil leaves powder on productive and physiological performance in growing Japanese quail. *Fayoum J. Agric. Res. Dev.* **2024**, *38*, 512–523. https://doi.org/10.21608/fjard.2024.301364.1056.
87. Afnan, R.; Ulupi, N. A Review: The Use of In Ovo Feeding in Various Types of Poultry. *J. Ilmu Produksi Dan Teknol. Has. Peternak.* **2023**, *11*, 67–72.
88. Sockman, K.W.; Schwabl, H. Yolk androgens reduce offspring survival. *Proc. R. Soc. Lond. Ser. B Biol. Sci.* **2000**, *267*, 1451–1456.
89. Abbas, R.J. Effect of using fenugreek, parsley and sweet basil seeds as feed additives on the performance of broiler chickens. *Int. J. Poult. Sci* **2010**, *9*, 278–282.
90. Al-Shaheen, S.A.; Abbas, R.J.; Majeed, T.I. Effect of different levels of basil and peppermint an essential oils on productive and physiological performance of two quail lines during egg production period. *Ann. For. Res.* **2023**, *66*, 2526–2546.
91. Sanjyal, S.; Sapkota, S. Supplementation of broilers diet with different sources of growth promoters. *Nepal J. Sci. Technol.* **2011**, *12*, 41–50.
92. Khattak, F.; Ronchi, A.; Castelli, P.; Sparks, N. Effects of natural blend of essential oil on growth performance, blood biochemistry, cecal morphology, and carcass quality of broiler chickens. *Poult. Sci.* **2014**, *93*, 132–137. https://doi.org/10.3382/ps.2013-03387.
93. Subha Ganguly, S.G. Herbal and plant derived natural products as growth promoting nutritional supplements for poultry birds: A review. *J. Pharm. Sci. Innov.* **2013**, *2*, 12–13.

94. Abbas, R.J.; AlShaheen, S.A.; Majeed, T.I. Effect of Different Levels of Basil and Peppermint an Essential Oils on Productive and Physiological Performance of Two Lines of Growing Quail (Coturnix Coturnix Japonica). *Biochem. Cell. Arch.* **2021**, *21*, 27–37.
95. Al-Kelabi, T.; Mohamed, M.F.; Rezaeian, M.; Al-Karagoly, H. Growth hormone and growth hormone receptor genes expression related with productive traits of broilers under the effectiveness of the sweet basil plant additive as a growth promoter. *Adv. Anim. Vet. Sci.* **2019**, *7*, 361–369.
96. ELnaggar, A.S.; El-Tahawy, W. Productive performance, physiological and immunological response of broiler chicks as affected by dietary aromatic plants and their essential oils. *Egypt. Poult. Sci. J.* **2018**, *38*, 773–795. https://doi.org/10.21608/epsj.2018.17104.
97. Jalal, B.J. The Effect of Supplement Dried Basil Leaves on Growth Performance Carcass Traits and Blood Parameters in Japanese Quail. Master's Thesis, Bingöl University, Bingöl, Turkey, 2017.
98. Sheoran, N.; Kumar, R.; Kumar, A.; Batra, K.; Sihag, S.; Maan, S.; Maan, N. Nutrigenomic evaluation of garlic (*Allium sativum*) and holy basil (*Ocimum sanctum*) leaf powder supplementation on growth performance and immune characteristics in broilers. *Vet. World* **2017**, *10*, 121–129. https://doi.org/10.14202/vetworld.2017.121-129.
99. Mohamed, F.; Elaziz, N. Impact of *Ocimum basilicum* leaves powder on immune response of chicken vaccinated against Newcastle Disease Virus. *Egypt. J. Agric. Res.* **2020**, *98*, 270–287. https://doi.org/10.21608/ejar.2020.118601.
100. Mohammed, Z.I.; Kadhim, K.S.; Taher, M.G. Effects of feeding different levels of *Ocimum basilicum* seeds on per-formance and immune traits of broiler. *J. Kerbala Agric. Sci.* **2017**, *4*, 249–258. https://doi.org/10.59658/jkas.v4i5.709.
101. Lee, P.; Fang-Ling, T.; Hsieh, K.; Wang, Y.; Liu, J.; Chen, Y.; Ye, J. Enhanced immune capability of white Roman geese by Ocimum gratissimum. *Orig. Orig. Contrib.* **2019**, *1*, 160.
102. Patel, S. Plant essential oils and allied volatile fractions as multifunctional additives in meat and fish-based food products: A review. *Food Addit. Contam. Part A* **2015**, *32*, 1049–1064. https://doi.org/10.1080/19440049.2015.1040081.
103. Stojanović-Radić, Z.; Pejčić, M.; Joković, N.; Jokanović, M.; Ivić, M.; Šojić, B.; Škaljac, S.; Stojanović, P.; Mihajilov-Krstev, T. Inhibition of Salmonella Enteritidis growth and storage stability in chicken meat treated with basil and rosemary essential oils alone or in combination. *Food Control* **2018**, *90*, 332–343.
104. Zolfaghari, A.; Firouzbakhsh, F. The effect of Basil (*Ocimum basilicum*) aqueous extract on growth changes, hematology and serum biochemical parameters in rainbow trout (Oncorhynchus mykiss). *J. Vet. Res.* **2013**, *68*, 397–404.
105. Gaio, I.; Saggiorato, A.G.; Treichel, H.; Cichoski, A.J.; Astolfi, V.; Cardoso, R.I.; Toniazzo, G.; Valduga, E.; Paroul, N.; Cansian, R.L. Antibacterial activity of basil essential oil (*Ocimum basilicum* L.) in Italian-type sausage. *J. Für Verbraucherschutz Und Leb.* **2015**, *10*, 323–329.
106. Barbosa, L.N.; Alves, F.C.B.; Andrade, B.F.M.T.; Albano, M.; Castilho, I.G.; Rall, V.L.M.; Athayde, N.B.; Delbem, N.L.C.; Roca, R.d.O.; Júnior, A.F. Effects of *Ocimum basilicum* Linn essential oil and sodium hexametaphosphate on the shelf life of fresh chicken sausage. *J. Food Prot.* **2014**, *77*, 981–986. https://doi.org/10.4315/0362-028X.JFP-13-498.
107. Nadeem, H.R.; Akhtar, S.; Ismail, T.; Qamar, M.; Sestili, P.; Saeed, W.; Azeem, M.; Esatbeyoglu, T. Antioxidant effect of *Ocimum basilicum* essential oil and its effect on cooking qualities of supplemented chicken nuggets. *Antioxidants* **2022**, *11*, 1882. https://doi.org/10.3390/antiox11101882.
108. Majdinasab, M.; Niakousari, M.; Shaghaghian, S.; Dehghani, H. Antimicrobial and antioxidant coating based on basil seed gum incorporated with Shirazi thyme and summer savory essential oils emulsions for shelf-life extension of refrigerated chicken fillets. *Food Hydrocoll.* **2020**, *108*, 106011. https://doi.org/10.1016/j.foodhyd.2020.106011.
109. Lugata, J.K.; Ndunguru, S.F.; Reda, G.K.; Ozsváth, X.E.; Angyal, E.; Czeglédi, L.; Gulyás, G.; Knop, R.; Oláh, J.; Mészár, Z. Methionine sources and genotype affect embryonic intestinal development, antioxidants, tight junctions, and growth-related gene expression in chickens. *Anim. Nutr.* **2024**, *16*, 218–230.
110. Zweil, H.S.; Zahran, S.M.; Ahmed, M.H.; El-Mabrok, B.M. Growth performance, carcass traits, immune response and antioxidant status of growing rabbits supplemented with peppermint and basil essential oils. *Egypt. Poult. Sci. J.* **2019**, *39*, 61–79. https://doi.org/10.21608/epsj.2019.28805.
111. Hoac, T.; Daun, C.; Trafikowska, U.; Zackrisson, J.; Åkesson, B. Influence of heat treatment on lipid oxidation and glutathione peroxidase activity in chicken and duck meat. *Innov. Food Sci. Emerg. Technol.* **2006**, *7*, 88–93. https://doi.org/10.1016/j.ifset.2005.10.001.
112. Amaral, A.B.; Silva, M.V.d.; Lannes, S.C.d.S. Lipid oxidation in meat: Mechanisms and protective factors–a review. *Food Sci. Technol.* **2018**, *38*, 1–15. https://doi.org/10.1590/fst.32518.
113. Wu, Y.; Wang, Y.; Yin, D.; Mahmood, T.; Yuan, J. Transcriptome analysis reveals a molecular understanding of nicotinamide and butyrate sodium on meat quality of broilers under high stocking density. *BMC Genom.* **2020**, *21*, 412. https://doi.org/10.1186/s12864-020-06827-0.

114. Zhang, W.; Marwan, A.H.; Samaraweera, H.; Lee, E.J.; Ahn, D.U. Breast meat quality of broiler chickens can be affected by managing the level of nitric oxide. *Poult. Sci.* **2013**, *92*, 3044–3049. https://doi.org/10.3382/ps.2013-03313.
115. Aziz, M.S.A.; Karboune, S. Natural antimicrobial/antioxidant agents in meat and poultry products as well as fruits and vegetables: A review. *Crit. Rev. Food Sci. Nutr.* **2016**, *58*, 486–511.
116. Ojeda-Piedra, S.A.; Zambrano-Zaragoza, M.L.; González-Reza, R.M.; García-Betanzos, C.I.; Real-Sandoval, S.A.; Quintanar-Guerrero, D. Nano-Encapsulated Essential Oils as a Preservation Strategy for Meat and Meat Products Storage. *Molecules* **2022**, *27*, 8187.
117. Amor, G.; Sabbah, M.; Caputo, L.; Idbella, M.; De Feo, V.; Porta, R.; Fechtali, T.; Mauriello, G. Basil essential oil: Composition, antimicrobial properties, and microencapsulation to produce active chitosan films for food packaging. *Foods* **2021**, *10*, 121. https://doi.org/10.3390/foods10010121.
118. Oliveira, G.d.S.; dos Santos, V.M.; Nascimento, S.T. Essential oils as sanitisers for hatching eggs. *World's Poult. Sci. J.* **2021**, *77*, 605–617.
119. El-Soufi, A.; Al Khatib, A.; Khazaal, S.; El Darra, N.; Raafat, K. Evaluation of essential oils as natural antibacterial agents for eggshell sanitization and quality preservation. *Processes* **2025**, *13*, 224. https://doi.org/10.3390/pr13010224.
120. Bekhet, G.M.; Khalifa, A.Y.Z. Essential oil sanitizers to sanitize hatching eggs. *J. Appl. Anim. Res.* **2022**, *50*, 695–701. https://doi.org/10.1080/09712119.2022.2138894.
121. Oliveira, G.d.S.; Nascimento, S.T.; dos Santos, V.M.; Silva, M.G. Clove essential oil in the sanitation of fertile eggs. *Poult. Sci.* **2021**, *100*, 5509–5516. https://doi.org/10.1016/j.psj.2021.101017.
122. Songsamoe, S.; Kabploy, K.; Khunjan, K.; Matan, N. The combined effect of green tea and peppermint oil against pathogenic bacteria to extend the shelf life of eggs at ambient temperature and the mode of action. *J. Food Saf.* **2022**, *42*, e12945. https://doi.org/10.1111/jfs.12945.
123. de Araújo, M.V.; Oliveira, G.d.S.; McManus, C.M.; Vale, I.R.R.; Salgado, C.B.; Pires, P.G.S.; de Campos, T.A.; Gonçalves, L.F.; Almeida, A.P.C.; Martins, G.d.S.; et al. Preserving the Internal Quality of Quail Eggs Using a Corn Starch-Based Coating Combined with Basil Essential Oil. *Processes* **2023**, *11*, 1612.
124. Suppakul, P.; Miltz, J.; Sonneveld, K.; Bigger, S.W. Antimicrobial properties of basil and its possible application in food packaging. *J. Agric. Food Chem.* **2003**, *51*, 3197–3207.
125. Oliveira, G.d.S.; McManus, C.; Santos, P.H.G.d.S.; de Sousa, D.E.R.; Jivago, J.L.d.P.R.; de Castro, M.B.; Dos Santos, V.M. Hatching egg sanitizers based on essential oils: Microbiological parameters, hatchability, and poultry health. *Antibiotics* **2024**, *13*, 1066. https://doi.org/10.3390/antibiotics13111066.
126. Davis, M.; Morishita, T.Y. Relative Ammonia Concentrations, Dust Concentrations, and Presence of Salmonella Species and Escherichia coli Inside and Outside Commercial Layer Facilities. *Avian Dis.* **2005**, *49*, 30–35.
127. Witkowska, D.; Sowińska, J. Identification of Microbial and Gaseous Contaminants in Poultry Farms and Developing Methods for Contamination Prevention at the Source. In *Poultry Science*; IntechOpen: London, UK, 2017. https://doi.org/10.5772/61986.
128. Witkowska, D.; Sowińska, J. The effectiveness of peppermint and thyme essential oil mist in reducing bacterial contamination in broiler houses. *Poult. Sci.* **2013**, *92*, 2834–2843. https://doi.org/10.3382/ps.2013-03147.
129. Ponomarenko, G.V.; Kovalenko, V.L.; Balatskiy, Y.O.; Ponomarenko, O.V.; Paliy, A.; Shulyak, S. Bactericidal efficiency of preparation based on essential oils used in aerosol disinfection in the presence of poultry. *Regul. Mech. Biosyst.* **2021**, *12*, 635–641. https://doi.org/10.15421/022187.
130. Al-Harbi, N.A.; Al Attar, N.M.; Hikal, D.M.; Mohamed, S.E.; Abdel Latef, A.A.H.; Ibrahim, A.A.; Abdein, M.A. Evaluation of insecticidal effects of plants essential oils extracted from basil, black seeds and lavender against Sitophilus oryzae. *Plants* **2021**, *10*, 829. https://doi.org/10.3390/plants10050829.
131. Kačániová, M.; Galovičová, L.; Borotová, P.; Vukovic, N.L.; Vukic, M.; Kunová, S.; Hanus, P.; Bakay, L.; Zagrobelna, E.; Kluz, M. Assessment of *Ocimum basilicum* essential oil anti-insect activity and antimicrobial protection in fruit and vegetable quality. *Plants* **2022**, *11*, 1030. https://doi.org/10.3390/plants11081030.
132. Chenni, M.; El Abed, D.; Neggaz, S.; Rakotomanomana, N.; Fernandez, X.; Chemat, F. Solvent free microwave extraction followed by encapsulation of O. basilicum L. essential oil for insecticide purpose. *J. Stored Prod. Res.* **2020**, *86*, 101575. https://doi.org/10.1016/j.jspr.2020.101575.
133. Chan, C.A.; Ho, L.Y.; Sit, N.W. Larvicidal activity and phytochemical profiling of sweet basil (*Ocimum basilicum* L.) leaf extract against Asian Tiger mosquito (*Aedes albopictus*). *Horticulturae* **2022**, *8*, 443. https://doi.org/10.3390/horticulturae8050443.
134. Magdaș, C.; Cernea, M.; Baciu, H.; Șuteu, E. Acaricidal effect of eleven essential oils against the poultry red mite Dermanyssus gallinae (Acari: Dermanyssidae). *Sci. Parasitol.* **2010**, *11*, 71–75.

135. Ye, Q.; Georges, N.; Selomulya, C. Microencapsulation of active ingredients in functional foods: From research stage to commercial food products. *Trends Food Sci. Technol.* **2018**, *78*, 167–179. https://doi.org/10.1016/j.tifs.2018.05.025.
136. Gorzin, M.; Saeidi, M.; Javidi, S.; Seow, E.-K.; Abedinia, A. Nanoencapsulation of Oliveria decumbens Vent./basil essential oils into gum arabic/maltodextrin: Improved in vitro bioaccessibility and minced beef meat safety. *Int. J. Biol. Macromol.* **2024**, *270*, 132288. https://doi.org/10.1016/j.ijbiomac.2024.132288.
137. Aboutalebzadeh, S.; Esmaeilzadeh-Kenari, R.; Jafarpour, A. Nano-encapsulation of sweet basil essential oil based on native gums and its application in controlling the oxidative stability of Kilka fish oil. *J. Food Meas. Charact.* **2022**, *16*, 2386–2399. https://doi.org/10.1007/s11694-022-01332-2.
138. Cai, M.; Wang, Y.; Wang, R.; Li, M.; Zhang, W.; Yu, J.; Hua, R. Antibacterial and antibiofilm activities of chitosan nanoparticles loaded with *Ocimum basilicum* L. essential oil. *Int. J. Biol. Macromol.* **2022**, *202*, 122–129. https://doi.org/10.1016/j.ijbiomac.2022.01.066.
139. Sutaphanit, P.; Chitprasert, P. Optimisation of microencapsulation of holy basil essential oil in gelatin by response surface methodology. *Food Chem.* **2014**, *150*, 313–320. https://doi.org/10.1016/j.foodchem.2013.10.159.
140. Paul, V.; Rai, D.C.; Pandhi, S.; Seth, A. Effect of coating materials for microencapsulation of basil oil using spray drying. *Med. Plants-Int. J. Phytomedicines Relat. Ind.* **2020**, *12*, 251–257.
141. Hamid, S.; Oukil, N.F.; Moussa, H.; Mahdjoub, M.M.; Djihad, N.; Berrabah, I.; Bouhenna, M.M.; Chebrouk, F.; Hentabli, M. Enhancing basil essential oil microencapsulation using pectin/casein biopolymers: Optimization through D-optimal design, controlled release modeling, and characterization. *Int. J. Biol. Macromol.* **2024**, *265*, 130948. https://doi.org/10.1016/j.ijbiomac.2024.130948.
142. Sampath, M.; Muguli, G.; Pai, S.; Babu, U. Techno-commercial application of microencapsulated basil oil and thyme oil and their antibacterial activity against aquatic pathogens. *Int. J. Fish. Aquat. Stud.* **2022**, *10*, 101–106. https://doi.org/10.22271/fish.2022.v10.i5b.2730.