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Medicinal Plants and Natural Substances for Poultry Health: A Review

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A B S T R A C T

The global poultry industry relies heavily on antibiotics to prevent and treat diseases and promote growth. However, the rise of antibiotic-resistant bacteria poses significant risks to both animal and human health, necessitating alternative approaches to maintain health and productivity. This review systematically examines the evidence for medicinal plants and their bioactive components as non-antibiotic interventions and growth promoters in poultry species. Numerous herbs, spices, plant extracts, essential oils, and isolated phytochemicals demonstrate beneficial bioactivities relevant to poultry production in vitro and in vivo, including antimicrobial, anti-inflammatory, immunomodulatory, and antioxidant effects. While considerable research confirms positive impacts on performance under experimental conditions, questions remain regarding bioavailability, mechanisms, efficacy, safety, feasibility, and suitability for commercial integration that currently impede widespread adoption as antibiotic alternatives. Further high-quality controlled trials directly analyzing physiological responses, production impacts, safety profiles, and cost-effectiveness analysis are warranted to support the integration of evidence-based phytogenic feed additives in poultry production systems.

Keywords: *phytotherapy, botanicals, herbs, antibiotics, antibiotic growth promoters, antibiotic resistance.*

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1 Introduction

AntibttTiotics and related antimicrobials have been widely used in commercial poultry production for disease treatment, prevention of infections, and growth promotion over the past several decades (1). Antibiotic growth promoters (AGPs) at sub-therapeutic have been routinely incorporated into poultry feed to improve feed efficiency and growth rates by altering gut microbial populations (2). However, while antibiotics provide health and productivity benefits, their extensive use has contributed to the emergence of drug-resistant bacteria. Resistant pathogens can then be transferred from poultry to humans, raising significant public health concerns (3).

In response to the risks of antibiotic resistance, many countries have introduced partial or complete bans on the use of AGPs and other antibiotics in livestock feed and water (4). For example, the European Union banned the use of AGPs in 2006 (5). The United States Food and Drug Administration introduced guidance in 2013 to phase out AGPs and bring remaining antibiotic uses in food animals under veterinary supervision (6). With increasing restrictions on sub-therapeutic antibiotic administration, identifying viable alternatives to maintain health and productivity has become an important focus of research in poultry medicine (7).

In response to the risks of antibiotic resistance, many countries have introduced partial or comprehensive bans on the use of antibiotic growth promoters in livestock production (8). The European Union began prohibiting AGPs in animal feed in 2006 (5). The United States Food and Drug Administration introduced guidance in 2013 to phase out AGPs and bring remaining antibiotic uses in food animals under veterinary supervision. Additional countries instituting partial or complete bans include Australia, Japan, and Taiwan (9).

While regulations aim to promote the judicious therapeutic use of antibiotics, limiting AGPs can negatively impact poultry health and performance if not replaced with effective alternatives. Thus, identifying novel non-antibiotic approaches to maintain productivity and prevent disease in poultry production systems is an important area of investigation. Using alternatives to antibiotics has been described as a "global social responsibility" by the poultry industry to reduce resistance risks (7, 10, 11).

One category of non-antibiotic approaches garnering interest is phytogenic feed additives derived from medicinal plants and botanical products. Plants used for centuries in herbal medicine contain a variety of bioactive secondary metabolites, including polyphenols, glycosides, alkaloids, and volatile oils, which can exert antimicrobial, anti-inflammatory, analgesic, antioxidant, and immunomodulatory effects. The long history of traditional phytotherapy use and understood biological activities make medicinal plant compounds promising options as substitutes for AGPs in poultry rations (12-14).

Medicinal plants and their bioactive components are now being investigated as potential alternatives to antibiotics and synthetic chemotherapeutics (15). Traditional medicine has historically used herbs, spices, and botanical extracts to treat a variety of human and animal ailments (16). Many plants contain pharmacologically active secondary metabolites such as polyphenols, flavonoids, alkaloids, and terpenoids which can exert beneficial effects through mechanisms including antibacterial, anti-inflammatory, immunomodulatory, and antioxidant properties (17). The long historical use and understood bioactivities make medicinal plants promising options as feed supplements for non-antibiotic approaches in poultry production (18).

A number of studies over the past two decades have evaluated the efficacy of various medicinal plants, extracts, essential oils, and isolated phytochemicals for improving poultry health, well-being, and productivity. Reported benefits include increased weight gain and feed efficiency, enhanced egg production and quality, greater resistance to bacterial and parasitic infections, anti-inflammatory effects, and reduced oxidative stress. Administration methods tested include incorporation into feed or water and individual dosing regimens (19, 20).

The aim of this review study was to systematically consolidate and evaluate the current scientific evidence for using medicinal plants and natural products to enhance poultry health, disease resistance, and productivity as alternatives to antibiotics and synthetic chemotherapeutics. It will summarize the breadth of plants, extracts, bioactive compounds, and modes of delivery studied in poultry species. Reported effects on growth performance, egg production, meat quality, gut health, and pathogen resistance will be analyzed. Proposed mechanisms of action and limitations of the existing research will be discussed. By reviewing and critically appraising the available literature, this article intends to identify promising phytotherapy strategies for poultry production, as well as research gaps to guide future investigations.

2 Methods

2.1 Literature Search Strategy

A systematic search of the published literature was conducted using the PubMed, Scopus, and Web of Science databases to identify relevant studies on the use of medicinal plants and natural products in poultry production. The following search terms were used in various combinations: (medicinal plant OR herbal medicine OR phytotherapy OR botanical OR phytochemical) AND (poultry OR chicken OR hen OR broiler OR layer OR chick* OR poult* OR turkey OR duck OR goose OR avian). Searches were limited to English-language publications in peer-reviewed academic journals. No date restrictions were imposed.

2.2 Inclusion and Exclusion Criteria

Studies were included in the review if they investigated medicinal plants, extracts, essential oils, or isolated phytochemicals administered to poultry and analyzed effects on health, growth, feed conversion, egg production, meat quality, gut microflora, or disease resistance. Both in vitro and in vivo studies were eligible for inclusion. Review articles, opinion pieces, conference abstracts, and duplicated publications were excluded. Studies investigating prebiotics, probiotics, synthetic compounds, and antibiotics were also excluded, as the focus was specifically on natural phytogenic substances as alternatives to antibiotics.

2.3 Data Extraction

Data extracted from the eligible studies included: first author and year, plant species used, parts of plants tested, bioactive components identified, poultry species and production type, route and duration of administration, dosage levels, measured outcome parameters, and pertinent results. Tables were generated to categorize findings based on the type of phytogenic intervention, including studies on whole plant products, extracts, essential oils, and isolated compounds. Outcomes were summarized by effects on growth performance, egg production, meat quality, gut health and microflora, immune response, disease resistance, safety, and toxicity concerns.

3 Antibiotic Use Patterns in Poultry Production

Antibiotics are administered to commercial poultry for therapeutic treatment of bacterial infections, prophylactic disease prevention in healthy flocks, and as feed additives to promote growth and feed efficiency (21). They can be delivered through water, injection, oral dosing, or feed. Veterinarians may prescribe antibiotics like penicillins, tetracyclines, sulfonamides, and macrolides to treat ill chickens diagnosed with pathogenic infections (22). However, much antibiotic use in poultry is for administration to flocks that show no clinical signs of illness (23).

Prophylactic antibiotics are continuously provided continuously in feed or water to reduce risks of infection and outbreaks in intensive production settings (2). Prophylaxis is primarily aimed at preventing the development of necrotic enteritis, a disease caused by overgrowth of the bacterium Clostridium perfringens which can cause significant morbidity and mortality. Antibiotics used prophylactically include bacitracin, virginiamycin, tylosin, and lincomycin. Prophylaxis involves longer duration but lower doses than therapy (24-26).

Sub-therapeutic antibiotic use refers to the incorporation of AGPs into poultry feed at doses well below those used for disease treatment (Gustafson and Bowen, 1997). AGPs have been routinely fed for growth promotion effects attributed to their influence on gut microbiota, nutrient absorption, and immune status. Common AGPs include bambermycin, penicillin, virginiamycin, tylosin, and bacitracin. While AGPs improve performance and economic returns, their extensive use has raised public health concerns over the selection of antibiotic-resistant bacteria (27-29).

3.1 Antibiotic Resistance Concerns with Nontherapeutic Use in Poultry

The administration of antibiotics, especially at low doses over prolonged periods, provides selective pressure that facilitates the development of resistant strains (30). In normal microbial populations, a small subset may harbor mutations or genes that enable them to withstand antibiotics and proliferate under selection pressure. Resistant bacteria can then spread between animals via direct contact, environmental routes, or the food chain. Several pathogenic species have developed multidrug resistance, complicating treatment in both veterinary and human medicine (31, 32).

Poultry are recognized as important reservoirs capable of transmitting antibiotic-resistant foodborne pathogens to humans, including non-typhoidal Salmonella and Campylobacter species (33). Most Campylobacter isolates from conventional poultry are now resistant to tetracyclines, lincosamides, penicillins, and fluoroquinolones (34). Fluoroquinolone-resistant Campylobacter jejuni is highly prevalent in retail chicken, with resistance attributed to enrofloxacin use in poultry (35). Multiple antibiotic-resistant variants of Salmonella have also emerged in poultry production, posing food safety risks (36).

Antibiotic-resistant bacterial infections increase morbidity and mortality in humans by compromising antibiotic therapy, lengthening hospitalizations for infection management, and necessitating alternative antimicrobials that may be less effective, more toxic, or more costly (37). Reducing nontherapeutic antibiotic use in livestock production has therefore become a public health priority to help preserve antibiotic efficacy in human medicine.

3.2 Regulations Restricting Nontherapeutic Antibiotic Use in Poultry

Concerns over accelerating antibiotic resistance have led many countries to ban or restrict antibiotic use for growth promotion and prophylaxis in food animals (5). The United States Food and Drug Administration introduced guidance in 2013 that requires pharmaceutical companies to voluntarily cease selling AGPs for growth promotion and to shift remaining uses to prescription or veterinary feed directive status for therapeutic indications only (38).

The FDA policy aims to bring all antibiotic administration in livestock under veterinary oversight to encourage more judicious use. This includes limiting preventative use to specific situations of heightened risk for the development of a particular bacterial infection, rather than continuous prophylaxis. Several medically important antibiotic classes have now been fully phased out as over-the-counter feed additives in the U.S., including penicillins, tetracyclines, macrolides, lincosamides, and streptogramins (39).

Some countries have imposed total bans on using antibiotics as growth promoters. For example, the sale of antimicrobial feed additives for growth promotion was prohibited in Norway beginning in 1995 (40). Strict restrictions on agricultural antibiotics have also been adopted in Denmark, Sweden, and the Netherlands. However, in the U.S. and some other countries, antibiotics can still be prescribed for disease prevention and therapy as regulated by recent policies. Although restrictions aim to promote more judicious therapeutic use in animals, reducing subtherapeutic administration could negatively impact health and productivity if viable alternatives are not available.

3.3 Impacts of Antibiotic Growth Promoter Restrictions on Poultry Health and Productivity

Eliminating antibiotic growth promoters and prophylaxis can adversely affect poultry health, performance, and mortality rates if not replaced by effective alternatives (5). AGPs provide measurable production benefits by inhibiting subclinical infections, reducing inflammation-induced gut integrity loss, lowering immune system activation, and enabling animals to achieve full genetic growth potential (41). Modeling suggests AGP prohibitions reduce broiler life weight by 2-5% depending on country-specific production practices, disease pressures, and alternative disease control measures (42).

Observed adverse impacts after AGP withdrawal include increased mortality, carcass condemnation, veterinary therapeutic use, production time, and flock heterogeneity (21). Removal of AGPs appears to allow increased proliferation of Clostridium perfringens, leading to higher incidence of necrotic enteritis, and impaired gut barrier function. This results in reduced growth rates, increased feed conversion ratios, diarrhea, and secondary infections. Economic losses attributed to AGP cessation have been estimated between 1-15% depending on species, pathogen load, vaccine use, and compensatory management changes (43-45).

Sub-therapeutic antibiotics modulate gut microbiota toward a favorable profile, reducing pathogens, virulence factors, and antigen load. Withdrawal allows pathogens like C. perfringens to proliferate, produce harmful toxins, and damage the intestinal lining (46). The resulting inflammatory insult impairs nutrient absorption and growth. Gut permeability changes also allow the translocation of immunogenic bacteria, endotoxins, and antigens that can lead to chronic immune activation. The suppressed immunity and inflammation from microbial imbalance and gut barrier disruption likely underlie much of the reduced performance observed after removing antibiotic growth promoters (47, 48).

While the reasons for detrimental impacts are not yet fully understood, it is clear that phasing out sub-therapeutic antibiotics poses health and productivity challenges for commercial poultry production. Implementing good management practices like vaccination, probiotics, and biosecurity measures can help offset adverse effects (49). However, identifying efficacious alternatives to maintain performance, control pathogens, support gut health, and modulate immunity remains an important field of research to ensure sustainable poultry production.

3.4 Integrative Health Management Strategies to Replace Antibiotic Growth Promoters

Various approaches exist to potentially replace the productivity-enhancing and prophylactic effects of antibiotics in poultry production:

Vaccines – Vaccinating against major viral, bacterial, and protozoan poultry diseases enhances protective immunity to reduce clinical and subclinical infections that impair growth (50). Effective vaccination provides defense against challenges like coccidiosis. However optimal timing and validated protocols are critical.

Probiotics - Administering beneficial bacteria can help competitively exclude pathogens, modulate immunity, and maintain gut barrier integrity (51). Combining probiotic species provides synergy. But product quality assurance and validated strains are needed.

Phytogenics – Plants contain a diversity of antimicrobial, antioxidant, and immunomodulatory metabolites that may provide alternatives to antibiotics for pathogen control, anti-inflammatory effects, and growth promotion (15). However, active compounds, efficacy, and optimal delivery require research.

Prebiotics – Non-digestible carbohydrates promote the growth of beneficial commensal bacteria, altering microbial profiles, metabolites, and immunity (52). However, effects are inconsistent and require characterization.

Micronutrients – Essential trace minerals like zinc, copper, and selenium contribute to antioxidant status, immunity, gut health, and enzyme functions (53). However, benefits beyond deficiency correction are debated.

Management – Heightened biosecurity measures, environmental enrichment, low-stress handling, and sanitary housing help reduce infection risks and stress-related immunosuppression (54). However, feasibility and compliance challenges exist.

Given the complex dynamics underlying poultry health and growth promotion, multi-component protocols combining judiciously selected antibiotics as needed for therapy with vaccines, pre-probiotics, phytogenics, micronutrients, and management practices may provide optimal alternative strategies to maintain productivity and confer robust protection against challenges in antibiotic-free flocks (49). Of particular interest are naturally derived phytochemicals with the potential to beneficially modulate gut health, immunity, and antioxidant status. The following sections review the evidence for using medicinal plants and bioactive compounds from traditional medicine as antibiotic alternatives in poultry production systems.

3.5 Medicinal Plants as Alternatives to Antibiotics

Medicinal plants and their isolated phytochemicals are increasingly being investigated as feed supplements to replace sub-therapeutic antibiotic use and maintain health and performance in commercial poultry and other livestock species (55). Traditional medicine systems utilized herbs, spices, and botanical extracts to treat diseases long before the introduction of synthetic pharmaceuticals (56). Many plants contain bioactive secondary metabolites such as polyphenols, alkaloids, glycosides, saponins, and volatile oils that can exert therapeutic effects through mechanisms including antimicrobial, anti-inflammatory, analgesic, immunomodulatory, and antioxidant properties (17).

The long history of traditional use provides a foundation to guide investigation of medicinal plants as viable options for non-antibiotic approaches in poultry production. Given rising consumer demand for organic, natural, and antibiotic-free animal products, phytogenic feed additives also align with environmental and ethical consumer preferences (15). If proven effective, functional, and economical, naturally-derived compounds could provide more acceptable alternatives to replace productivity-enhancing antibiotics. The following sections review the existing research on medicinal plant products for improving health parameters, growth, egg production, meat quality, and pathogen control in poultry species (20, 57, 58).

4 Plants and Phytochemicals Investigated in Poultry

A broad range of medicinal herbs, spices, fruit and plant extracts, essential oils, and isolated phytochemicals derived from traditional medicine systems have been screened in vitro and analyzed through in vivo feeding trials for their effects on poultry health and productivity (59). These include:

- Whole herbs/spices: Basil, thyme, oregano, cumin, ginger, cinnamon, pepper, garlic, licorice, ginseng, turmeric root
- Fruit extracts: Pomegranate, date, fig, olive, grape seed, cranberry
- Plant extracts: Neem, moringa, marigold, echinacea, ginseng, green tea, holy basil
- Essential oils: Oregano, thyme, cinnamon, pepper, anise, lemon, frankincense

- Components: Carvacrol, cinnamaldehyde, capsaicin, allicin, gingerol, curcumin, quercetin, ursolic acid.

Some of the most extensively researched plants, extracts, and bioactive compounds include garlic, ginger, black cumin, turmeric, oregano, thyme, cinnamon, chili/capsicum, yucca, licorice, cranberry, anise, eucalyptus, marigold, and Echinacea (55, 60). Of these, certain plants and compounds have shown particular promise in enhancing parameters such as body weight, egg production, antioxidant status, immunity, gut health, and pathogen control. The following sections summarize some of the key medicinal plants and their major bioactive components that have been evaluated in poultry systems (58, 61, 62). Some of plants and compounds with extensive research in poultry industry is shown in Table 1.

Table 1. Plants and compounds with extensive research in poultry.

Plant	Plant Parts Used	Bird Type	Route	Key Effects	Reference
Garlic	Bulb	Poultry	Feed	Antimicrobial, antioxidant, growth promoter	(63-65)
Ginger	Rhizome	Poultry	Feed	Antioxidant, growth promoter	(19, 66-68)
Turmeric	Rhizome	Poultry	Feed	Antioxidant, immunomodulatory	(69, 70)
Chili Pepper	Fruit	Poultry	Feed	Anti-coccidial, immunomodulatory	(71)
Echinacea	Aerial parts	Poultry	Feed	Immunostimulant	(72)
Oregano	Leaves	Poultry	Feed	Antimicrobial	(73)
Thyme	Leaves	Poultry	Feed	Antioxidant, immunomodulatory	(74)
Cinnamon	Bark	Poultry	Feed	Antimicrobial, anti-coccidial	(75)
Yucca	Roots	Poultry	Feed	Immunostimulant	(76)
Eucalyptus	Leaves	Poultry	Feed	Anti-inflammatory	(77)
Rosemary	Leaves	Poultry	Feed	Antioxidant, immunomodulatory	(57)
Anise	Seeds	Poultry	Feed	Antioxidant, immunomodulatory	(78)
Peppermint	Leaves	Poultry	Feed	Antibacterial, growth promoter	(79)
Fennel	Seeds	Poultry	Feed	Antioxidant, antimicrobial	(80)
Sage	Leaves	Poultry	Feed	Antioxidant	(81)
Clove	Flower buds	Poultry	Feed	Anti-inflammatory, antimicrobial	(82)
Black cumin	Seeds	Poultry	Feed	Antioxidant, immunomodulatory	(83)
Fenugreek	Seeds	Poultry	Feed	Hypoglycemic, hypolipidemic	(84)
Ginseng	Roots	Poultry	Feed	Anti-stress, immunostimulant	(85)
Green tea	Leaves	Poultry	Feed	Antioxidant, anti-coccidial	(86)
Bitter melon	Fruit	Poultry	Feed	Hypoglycemic, immunomodulatory	(87)
Neem	Leaves, seeds	Poultry	Feed	Antifungal, antiviral	(88)
Milk thistle	Seeds	Poultry	Feed	Hepatoprotective, antioxidant	(89)
Artemisia	Leaves	Poultry	Feed	Anti-coccidial	(90)
Garlic chives	Leaves	Poultry	Feed	Antimicrobial, antioxidant	(91)
Holy basil	Leaves	Poultry	Feed	Anti-inflammatory, antibacterial	(92)
Licorice	Roots	Poultry	Feed	Anti-inflammatory, antioxidant	(93)
Marigold	Flowers	Poultry	Feed	Antioxidant, pigmenter	(94)
Moringa	Leaves	Poultry	Feed	Antioxidant, hepatoprotective	(95)

5 Summary of Key Plants and Their Bioactive Components

The preceding sections highlighted the broad range of medicinal plants, extracts, essential oils, and isolated phytochemicals that have been evaluated for their potential to improve health and productivity in poultry species. While many plants demonstrate beneficial bioactivities, some key genera and their primary bioactive components can be summarized as follows based on the extent of research and reported impacts (Table 2):

Table 2. Summary of key plants and their bioactive components

Extract	Source	Extraction Solvent	Bird Type	Route	Key Effects	Major Components	Reference
Garlic extract	Allium species bulbs	Not specified	Poultry	Feed	Antimicrobial, antioxidant, immunostimulant	Allicin, organosulfides	(64)
Ginger extract	Zingiber officinale rhizomes	Not specified	Poultry	Feed	Anti-inflammatory, antioxidant	Gingerols, shogaols	(68)
Turmeric extract	Curcuma longa rhizomes	Not specified	Poultry	Feed	Anti-inflammatory, antioxidant	Curcumin	(70)
Chili pepper extract	Capsicum annum fruits	Not specified	Poultry	Feed	Analgesic, anti-coccidial	Capsaicin	(71)
Oregano extract	Origanum vulgare leaves	Not specified	Poultry	Feed	Antimicrobial	Carvacrol, thymol	(73)
Cinnamon extract	Cinnamomum verum bark	Not specified	Poultry	Feed	Anti-parasitic, antioxidant	Cinnamaldehyde	(75)
Echinacea extract	Echinacea purpurea aerial parts	Not specified	Poultry	Feed	Immunostimulant	Alkylamides, polysaccharides	(72)
Neem extract	Azadirachta indica leaves, seeds	Not specified	Poultry	Feed	Anti-parasitic, antiviral	Azadirachtin, nimbin	(88)
Green tea extract	Camellia sinensis leaves	Water, ethanol	Poultry	Feed	Antioxidant, antimicrobial	Catechins, EGCG	(86)
Garlic chives extract	Allium tuberosum leaves	Not specified	Poultry	Feed	Antimicrobial, antioxidant	Allicin, organosulfides	(91)
Anise extract	Pimpinella anisum seeds	Not specified	Poultry	Feed	Anti-inflammatory, antioxidant	Anethole	(78)

5.1 Feed Supplementation

The most common method of administering medicinal plants to poultry is through direct incorporation into feed as dietary supplements (68). Mixing dried and ground aerial parts like leaves, flowers, seeds, roots, or barks allows flock-wide delivery when voluntarily consumed via standard feeding regimens (96). Reported inclusion levels range from 1-5% for dried crude plant materials, though concentrations up to 10% have been tested to discern effects, which may exceed commercially feasible intakes (97). More potent forms like hydroalcoholic, aqueous, or ethanolic extracts are typically included at 0.05-0.5% of finished feed. Essential oils derived from steam distillation require even lower supplementation levels of 0.01-0.1% due to their high bioactive density and potential to impart flavor (98).

To overcome issues with stability and strong taste, microencapsulation techniques can help mask flavors while preventing the volatility of oils and sensitive compounds (99). Combining multiple complementary botanical extracts or essential oils at reduced individual doses may provide synergy, but possible negative interactions must also be assessed through efficacy and safety evaluations (100). Proper storage trials are prudent to determine stability over time for commercial feeds containing labile plant phytochemicals.

5.2 Water Supplementation

In addition to direct feed amendment, administering soluble medicinal plant extracts, essential oils, or powdered herb suspensions via drinking water provides an alternate delivery method (101). This allows easy preparation and uniform flock-wide intake. However, consistency in delivered doses can be challenging as actual consumption varies based on environmental factors and palatability. Therefore, close monitoring of preparation concentrations, water intake, and residual volumes is necessary to determine true ingestion (102).

5.3 Individual Dosing

While impractical for commercial flocks, direct individual administration techniques like oral gavage or adding measured doses into individual feed allotments support precision dosing for controlled research trials. This eliminates variability between birds and reliance on voluntary intake when discerning efficacy and mechanisms of action for medicinal plants (103). However, the extensive labor requirements make individual dosing unsuitable for practical commercial application.

5.4 *Anti-inflammatory and Analgesic Effects*

Several medicinal plants and their bioactive components have exhibited anti-inflammatory and pain-relieving properties in poultry. According to (96), chronic inflammation impairs growth, nutrient absorption, behavior, and immunity in chickens. Curcumin from turmeric suppresses pro-inflammatory cytokines like TNF-α and IL-1β by downregulating NF-kB signaling cascades (104). Gingerols in ginger inhibit COX-2 and lipoxygenase enzymes involved in inflammatory mediator synthesis (105). Capsaicin from chili peppers mediates analgesic effects by depleting neuropeptides like substance P that transmit pain signals (106). Additional herbs with anti-inflammatory activities include holy basil, licorice, green tea, garlic, and cinnamon (93). However, (17) note that further research should investigate the bioavailability, pharmacokinetics, mechanisms, and clinical benefits of isolated anti-inflammatory phytochemicals in poultry species.

5.5 *Antimicrobial and Anti-parasitic Effects*

Numerous plant compounds exhibit direct growth inhibition or inactivation of pathogens through mechanisms like membrane disruption, virulence factor suppression, and interference with parasite lifecycles (107). For example, carvacrol and thymol in oregano and thyme oils permeabilize bacterial membranes and inhibit efflux pumps (108). Allicin from garlic blocks cysteine protease activity vital for protozoal survival and reproduction (109). However, (110) state that additional in vivo studies are needed to fully evaluate antimicrobial and anti-parasitic efficacy, safety, bioavailability, and potential to counter resistance among poultry isolates.

5.6 *Modulation of Gut Microflora*

Specific phytogenic compounds may benefit poultry performance by modulating gastrointestinal microbial populations through selective toxicity to pathogens and prebiotic-like promotion of beneficial microbiota (111). However, (96) notes that research directly analyzing microbiome impacts of medicinal plants in poultry is currently limited. Culture-independent techniques could better elucidate shifts in microbial communities, metabolites, and inflammation markers (112).

5.7 *Immunomodulatory Effects*

Various herbs and isolated phytochemicals exhibit immunostimulatory properties by activating phagocytes, T cells, B cells, and natural killer cells involved in innate and adaptive immunity (85). Echinacea, garlic, ginger, and holy basil upregulated measures of humoral and cell-mediated immunity in poultry (55). However, (113) states that few in vivo studies directly evaluate immunological markers in response to phytogenic supplementation. Elucidating bioactive compounds, pharmacokinetics, and mechanisms warrants further investigation.

5.8 *Antioxidant Effects*

Dietary phytochemicals like polyphenols and carotenoids mitigate free radical damage through activities like hydrogen donation and glutathione upregulation (114). Herbs including turmeric, thyme, cinnamon and oregano improved antioxidant status and reduced oxidative markers in poultry tissues and eggs. However, (115) note that research is still needed on factors influencing in vivo bioavailability and efficacy of natural antioxidants.

6 Effects on Production Parameters

6.1 *Growth Promotion*

Multiple studies have demonstrated garlic supplementation significantly improves weight gain and feed efficiency in broilers compared to unsupplemented controls (101). Proposed mechanisms for garlic's growth-promoting effects include inhibition of pathogenic bacteria like E. coli and Salmonella, reduction of pro-inflammatory compounds that depress growth, and enhanced digestion and absorption of nutrients like proteins and minerals (112). Typical supplementation levels around 1-2% provided the greatest enhancements in body weight gain and feed conversion ratio (97).

Ginger and its bioactive components like gingerols and shogaols have also exhibited growth-stimulating properties in broilers attributed to appetite enhancement, increased gastric secretions, and anti-inflammatory effects in the gastrointestinal tract (116). Dried ginger powder supplemented at 5 g/kg feed significantly increased body weight gain in broilers by up to 12% compared to non-supplemented controls (117). The gingerols are believed to enhance protein and mineral absorption and digestion.

Cinnamon oil and cinnamaldehyde improved weight gain and feed efficiency in broilers infected with Eimeria parasites or Clostridium bacteria, indicating anticoccidial and antimicrobial mechanisms. Cinnamon oil provided at 100-200 mg/kg feed increased growth performance in challenged broilers to match healthy controls (118).

6.2 Feed Intake and Conversion

Multiple controlled studies report capsaicin and capsicum oleoresin supplementation significantly increased voluntary feed intake in broilers compared to standard diets, potentially by stimulating digestive secretions and blood flow (71). Capsaicin provided at 200 mg/kg increased feed consumption by up to 15%, which could translate into greater growth rates (119).

Garlic, ginger, thyme, turmeric, black cumin, licorice, and yucca saponins reduced feed conversion ratio in broilers by 3-10%, indicating improved digestive efficiency and less wasted feed (120). Enhanced protein, mineral and energy digestibility are believed to be responsible, though exact mechanisms require further elucidation.

6.3 Egg Production and Quality

Multiple controlled studies indicate garlic powder or extract supplementation significantly increased egg production rate, egg weight, shell thickness and mass output in laying hens compared to unsupplemented controls (78). Garlic provided at 1-2% of feed increased total egg numbers per hen by approximately 8-15% over a 6-8week trial. Enhanced nutrient absorption, antioxidant status, and liver health are proposed mechanisms though require further analysis.

Dried ginger powder supplementation at 5 g/kg feed significantly increased egg weight and total mass output in laying hens by up to 12.8% over 6 weeks (120). The gingerols likely improve protein and mineral absorption and digestion. Marigold extract also increased egg yolk carotenoid content and color score.

6.4 Meat Quality

Rosemary leaves contain rosmarinic acid and carnosic acid that inhibit lipid oxidation in broiler meat during refrigerated storage, preventing rancidity development. Rosemary decreased production of secondary lipid oxidation compounds like hexanal by up to 32% compared to control meat. The enhanced antioxidant capacity extended shelf life (121).

Turmeric supplementation altered breast meat composition in broilers toward increased moisture content and higher unsaturated fatty acids, which could improve sensory properties (96). Meat from turmeric-fed broilers had higher polyunsaturated fats and lower saturated fats. However, consumer sensory analysis is still needed.

6.5 Toxicity and Safety Concerns

Excessively high doses of some medicinal plant oils and extracts can impair liver function in chickens. Oregano and thyme oils provided at over 200 mg/kg feed induced mild hepatic lesions and increased serum enzymes indicative of liver damage (98). Clove doses exceeding 400 mg/kg also negatively impacted performance measures like growth and feed intake, potentially due to toxicity and nutrient interactions reducing digestibility (122). Further research should continue to identify toxicity thresholds.

Limited residue studies suggest bioaccumulation risks are low for typical supplementation levels, but some lipid-soluble compounds could accumulate at higher (102). Curcumin fed at 5 g/kg did result in measurable liver residues post-mortem, though rapid depletion also occurred (123). Additional residue kinetics trials and sensitive analytical screening methods would support science-based safety controls.

7 Conclusions and Future Directions

7.1 Knowledge Gaps and Areas for Future Research

While a broad range of medicinal plants have shown beneficial bioactivities in poultry, there remain considerable knowledge gaps constraining conclusive assessment of viability as antibiotic alternatives. Targeted research in the following areas would help address the limitations of the current evidence base:

- Dose-response trials to identify optimal supplementation levels balancing efficacy, cost, and toxicity
- Analyses of active constituent pharmacokinetics and bioavailability in target poultry tissues
- Elucidation of mechanisms of action through omics and assessment of gastrointestinal, immunologic, and physiologic impacts
- Rigorously controlled long-term productivity studies under commercial conditions
- Systematic safety and toxicity evaluations, including maximum tolerated doses

- Depletion studies and sensitive quantification of residues in poultry products
- Investigation of potential herb-drug interactions
- Cost-benefit and process feasibility analysis for commercial formulation
- Sensory and shelf-life impacts on final poultry products

By undertaking controlled trials focused on addressing these research gaps, the viability of prioritized medicinal plants and bioactive compounds as feed supplements in poultry production systems can be better established to support evidence-based use as antibiotic alternatives.

7.2 Feasibility for Commercial Adoption

Realizing viable commercial integration of scientifically proven medicinal plant additives in poultry will require addressing feasibility factors including:

- Establishing reliable, large-scale sourcing and extraction
- Developing cost-efficient stabilization, delivery, and formulation technologies
- Regulatory approval pathways for feed additives lacking drug oversight frameworks
- Industry acceptance and marketing incentives for phytogenic supplements
- Cost-benefit analysis indicating productivity enhancements offset input costs

While in vivo efficacy studies are still needed, additional work can begin assessing and addressing challenges for real-world adoption. Partnerships between research institutions, phytotherapy suppliers, feed manufacturers, poultry producers, and regulatory agencies can support a roadmap for the feasible integration of suitable medicinal plant compounds. With prudent evidence synthesis and translation, phytochemical feed additives could provide poultry production with approved, commercially viable antibiotic alternatives.

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Conflict of Interest

The authors declared no conflicts of interest.

Author Contributions

Mohsen Pashaei: Writing an article and doing a search; Zeroual Fayçal: Identification of suitable plant compounds for poultry feeding; Danial Kahrizi: Identification of anti-inflammatory and analgesic effects; Sezai Ercişli: Identification of antimicrobial and anti-parasitic effects.

Data Availability Statement

Data are available from the corresponding author upon reasonable request.

Ethical Considerations

Considering that this is a review article and research work has not been done on humans or animals, there was no need for the approval of the ethics committee.

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