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-Invited Review-

Benefits and Mechanisms of Phytobiotics Feed Additives in Poultry Production

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ABSTRACT

Increasing antimicrobial resistance has accelerated the exploration of phytobiotics as natural and sustainable feed additives to replace antibiotic growth promoters (AGPs) in poultry production. The antimicrobial, antioxidant, anti-inflammatory, and immunomodulatory effects of phytobiotics such as flavonoids, alkaloids, polyphenols, saponins, and essential oils from plants enhance the health and productivity of poultry. This review aimed to provide a comprehensive overview of the mechanisms and the beneficial effects of phytobiotics on antioxidant activity, immune responses, intestinal morphology, gut barrier integrity, gut microbiota modulation, and production performance in poultry. Phytobiotics enhance antioxidant defense through free radical scavenging activity and activation of endogenous antioxidant enzymes via the Nrf2 signaling pathway. Moreover, phytobiotics regulate cytokine expression, modulating immune responses, thereby increasing disease resistance and maintaining physiological homeostasis. Phytobiotics improve intestinal health by inhibiting pathogenic bacteria, promoting beneficial microbiota, increasing short-chain fatty acid production, and reinforcing tight junction proteins, leading to improved villous surface area and nutrient absorption efficiency. Studies have shown positive effects of phytobiotic inclusion on growth performance, egg production, intestinal health, and oxidative status in poultry. However, the efficacy of phytobiotics can be reduced during processing and storage as a result of thermal degradation, oxidation, and instability of bioactive compounds, which can reduce their antioxidant activity and biological functions in poultry. Nevertheless, phytobiotics remain promising as natural replacements for AGPs in enhancing poultry health, physiological status, intestinal function, and production performance in sustainable poultry production systems by modulating immune responses, improving antioxidant defense, maintaining intestinal morphology and gut barrier integrity, and promoting a balanced gut microbiota.

Keywords: antibiotic growth promoters; antioxidant; phytobiotics; poultry; gut microbiota

INTRODUCTION

The application of phytobiotics or plant-derived bioactive substances such as polyphenols, flavonoids, alkaloids, saponins, and essential oils has become a major focus in modern poultry nutrition as an alternative substitute to antibiotic growth promoters (AGPs). The rising occurrence of antimicrobial resistance has resulted in the banning of AGPs, promoting the development of nutrition programs based on natural, safe, effective, and sustainable ingredients. Additionally, tropical environmental conditions with high temperatures and humidity, as well as climate change-driven increases in ambient temperature, significantly raise the risk of heat stress in poultry. These conditions can disrupt physiological balance, decrease productive performance, impair immunological function, and increase vulnerability to pathogenic microbial infections (Hafeez *et al.*, 2016; Sumiati *et al.*, 2025). Therefore, phytobiotic application is a promising nutritional method to enhance the sustained health and production of chickens.

Phytobiotics also boost the performance of poultry production through improved intestinal health, improved immunological status, antioxidant activity, and preservation of physiological homeostasis (Hafeez *et al.*, 2016). Phytobiotics act as antimicrobials that inhibit pathogenic bacterial populations such as *Salmonella* spp. and *E. coli*, while enhancing beneficial bacteria growth such as *Bifidobacterium* and *Lactobacillus*. This promotes a balanced microbiota and enhanced poultry performance (Singh *et al.*, 2025; Wang *et al.*, 2025). Moreover, chickens under environmental or metabolic stress release excessive free radicals that contribute to oxidative stress with severe effects on health and productivity. The high antioxidant activity of phytobiotic substances such as polyphenols and flavonoids is attributed to their ability to scavenge free radicals and increase the activity of endogenous antioxidant enzymes (Bas, 2026). Phytobiotics can modulate immune responses through cytokine expression regulation, lymphocyte proliferation, and macrophage activity stimulation, thus enhancing disease resistance in poultry (Evrendilek, 2026; Pourhossein *et al.*, 2019). Furthermore, phytobiotics have been found to improve the intestinal barrier and intestinal morphology, including increased villus length and surface area, and villus length-to-crypt depth ratio, which is positively associated with higher nutrient absorption capacity and feed efficiency (Song *et al.*, 2024; Belote *et al.*, 2023).

Many studies have revealed the positive effects of phytobiotics on poultry performance. Phytobiotic compounds derived from fruits, seeds, leaves, flowers, peels, roots, and whole plants are used for their defense against biotic or abiotic factors. These plant materials are rich in bioactive compounds such as polyphenols, flavonoids, alkaloids, terpenoids, saponins, and essential oils, which collectively possess antioxidant, antimicrobial, anti-inflammatory, and immunomodulatory activities and have been shown to improve physiological conditions, digestive health, and poultry performance. For example, chestnut flower extract with strong antioxidant and antimicrobial properties has been shown to increase body weight, villous surface area, and the beneficial intestinal microbial population (Ozturk *et al.*, 2026). Likewise, supplementation of turmeric powder, which is rich in polyphenols, enhanced the health status of ducks (Nova and Yellita, 2015). Another study showed that dietary supplementation with *Andrographis paniculata* leaf meal, which contains terpenoids, improved egg production in laying hens (Yulianti *et al.*, 2015). A similar result was reported by Pradipta *et al.* (2019), where a combination of garlic and turmeric improved egg production and egg weight. Also, feeding *Olea europaea* leaf extract with high phenolic content improved broiler performance and intestinal health (Erener *et al.*, 2020). Although the benefits of phytobiotics on poultry performance have been reported in several review studies, most previous studies have discussed antioxidant activity, immune modulation, intestinal morphology and gut microbiota as separate topics rather than as interconnected biological processes. Consequently, the interactions between phytobiotics, the immune system, gut microbiota, antioxidant defense and intestinal integrity are still not fully understood. Furthermore, the characteristics of the phytobiotics can differ and lead to differences in biological responses, which poses a continuing challenge to determining the optimal formulations and dosages of phytobiotics in their application in the poultry industry. Moreover, the action mechanism of phytobiotics, with complex interactions between gut microbiota, the immune system, and antioxidant activity, should be studied more in depth to ensure constant effectiveness. Therefore, the aim of this review is to provide a comprehensive overview of the mechanisms of phytobiotics in improving poultry performance by modulating immune responses, increasing antioxidant capacity, maintaining intestinal barrier integrity and morphology, and controlling intestinal microbiota.

MATERIALS AND METHODS

This qualitative review employed a literature search based on the PRISMA framework (Rethlefsen *et al.*, 2021). The articles were retrieved from the databases of Scopus, PubMed, and ScienceDirect between 2016 and 2026 using the following combination of keywords: (“phytobiotic” OR “phytogenic” OR“ plant bioactive compound”) AND (“layer” OR “broiler” OR “quail” OR “duck”) AND (“gut health” OR “immune response” OR “antioxidant activity” OR “intestinal barrier” OR “intestinal morphology” OR “gut microbiota” OR “growth performance” OR “egg production”).

The inclusion criteria consisted of *in vivo* studies in poultry with phytobiotics and parameters referring to immune response, antioxidant function, intestinal barrier integrity, intestinal morphology, and gut microbiota. Articles were excluded if they were irrelevant, incomplete, or duplicates. Non-English articles were also excluded. English language publications were selected for more consistent scientific indexing. The studies also critically discussed the consistency of the findings and the factors influencing the efficacy of phytobiotics in improving poultry performance. A flowchart of the literature search and article selection process is presented in Figure 1.

MECHANISMS OF PHYTOBIOTICS IN POULTRY

The effects of phytobiotics on poultry health and production performance occur mainly through various interconnected biological pathways, including antioxidant activity, immune modulation, regulation of the intestinal microbiota, and maintenance of barrier integrity and intestinal morphology. Collectively, these processes maintain gut health, improve nutrient digestion and absorption, enhance resistance to oxidative and pathogenic stress, and ultimately promote optimal poultry productivity. Moreover, the interaction between these physiological pathways suggests that the efficacy of phytobiotics is not based on a single mode of action but on their combined effects at the molecular, cellular, and intestinal levels. The synergy of phytobiotics at the molecular level may be due to the complementary effects of different bioactive compounds, which act on a number of interconnected targets. Instead of acting via a single pathway, these compounds may simultaneously impact redox regulation, inflammatory signaling, and microbial cellular processes through pathways involving Nrf2/Keap1, NF-κB, bacterial cell membranes, DNA/RNA replication and transcription, and protein synthesis (Ma *et al.*, 2021; Wu *et al.*, 2022; Zhang *et al.*, 2025). These molecular interactions can trigger cellular responses involving antioxidant defense, regulation of inflammation, epithelial cell integrity, and immune cell function, which collectively contribute to gut health (Evrendilek, 2026). Thus, an in-depth understanding of these biological pathways is required to understand the functional roles of phytobiotics in poultry production

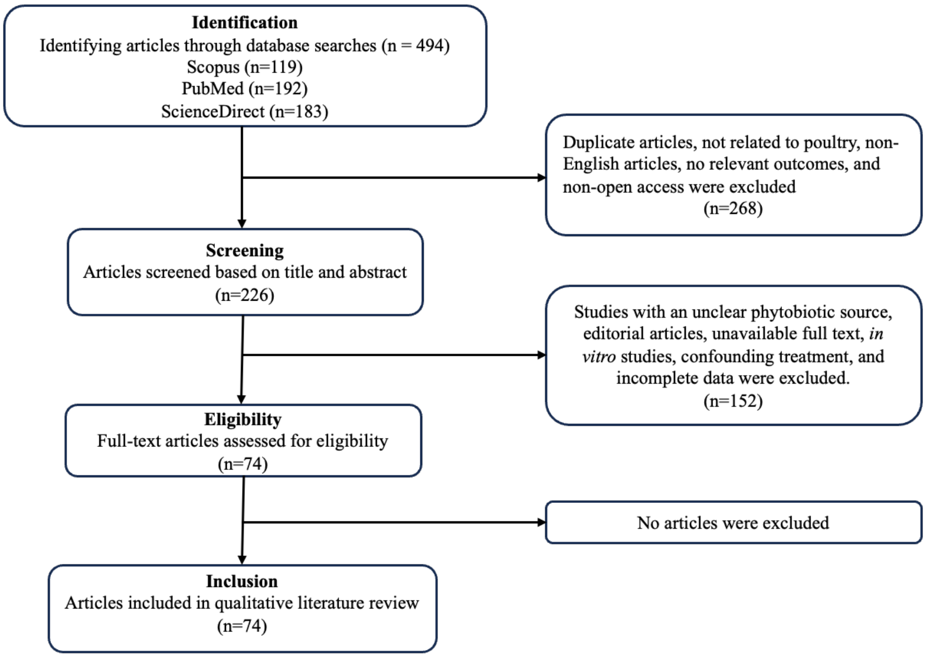

Figure 1. Flowchart of the literature search and article selection process

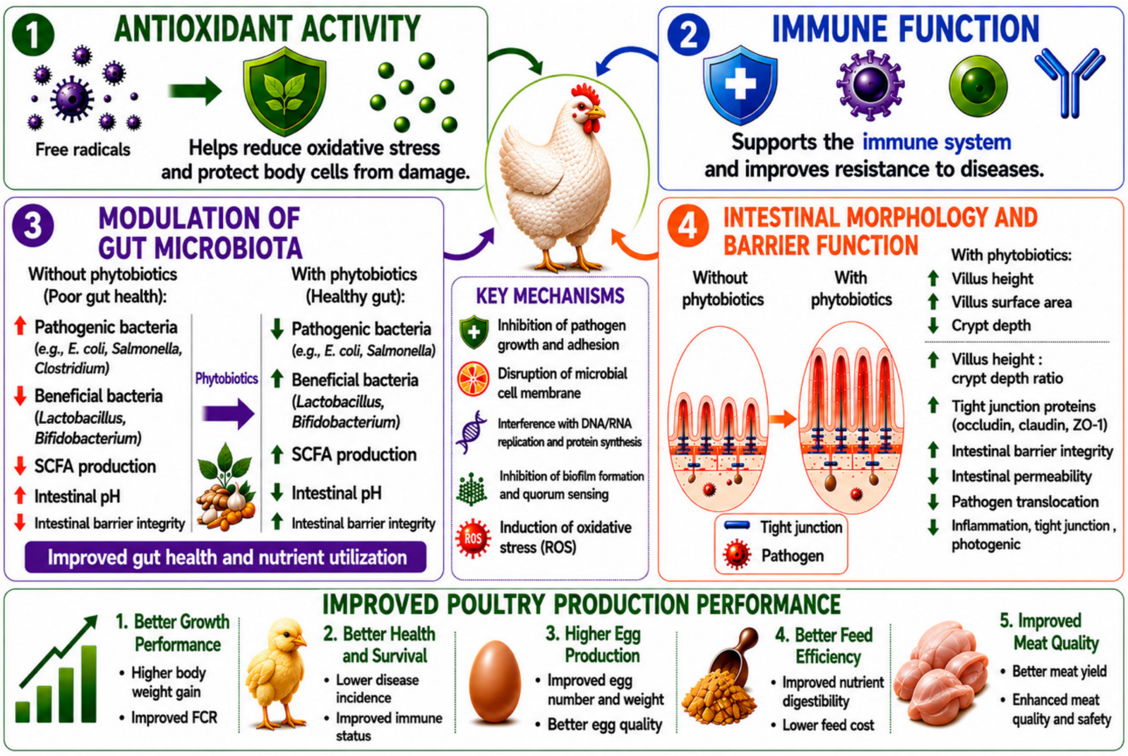

Figure 2. The mechanism of phytobiotic in enhancing poultry performance. Phytobiotics improve antioxidant capacity, modulate immune responses, maintain intestinal morphology and gut barrier integrity, and regulate gut microbiota to enhance nutrient absorption, health status, and production performance (Pourhossein *et al.*, 2019; Song *et al.*, 2024; Evrendilek, 2026).

systems. The main pathways of phytobiotics' action in poultry are presented in Figure 2.

Antioxidant Activity of Phytobiotics

Oxidative stress is one of the most important factors affecting health and productive performance in poultry, primarily due to exposure to environmental stressors such as high temperatures, high stocking density, and pathogenic problems. Oxidative stress results in the production of reactive oxygen species (ROS), causing biomolecular damage such as lipid peroxidation, protein oxidation, and DNA damage (Han & Lee, 2022).

Phytobiotics provide beneficial effects in these situations through two main pathways: direct and indirect antioxidant actions. Directly, flavonoids and polyphenols serve as free radical scavengers by giving electrons to stabilize ROS, thus preventing free radical chain reactions (Bas, 2026). Phytobiotics also regulate the endogenous antioxidant defense system indirectly by activating molecular pathways, especially the nuclear factor erythroid 2-related factor 2 (Nrf2) pathway. This pathway plays a crucial role in the regulation of redox balance, detoxification activities, and modulation of the immunological response of host cells. Under oxidative stress, the activation pathway is triggered by dissociation of Nrf2 from its cytoplasmic inhibitor, Kelch-like ECH-associated protein 1 (Keap1). Following release, Nrf2 translocates to the nucleus and upregulates the expression of antioxidant genes such as glutathione peroxidase (GPx), superoxide dismutase (SOD), and catalase (CAT) (Kikusato, 2021; Ma *et al.*, 2021).

Phytobiotic supplementation has been shown to increase the activity of antioxidant enzymes in several investigations. For instance, Zhang *et al.* (2018) and Zhang *et al.* (2015) observed that treatment of heat-stressed broilers with curcumin resulted in decreased malondialdehyde (MDA) levels and increased SOD and GPx activity via activation of the Nrf2 pathway. Similarly, Shen *et al.* (2019) reported that the bamboo leaf extract rich in polyphenols in the diet enhanced the overall antioxidant capacity of breast meat via Nrf2 activation. Green tea extract is a catechins source, especially epigallocatechin gallate, which has similarly been shown to increase the activity of antioxidant enzymes and defend tissues against oxidative damage (Simoni *et al.*, 2025). Essential oils from thyme and oregano are rich in carvacrol and thymol, which also play important roles in the antioxidant system. These compounds significantly increased total antioxidant capacity, superoxide dismutase, and glutathione peroxidase activities by up to approximately 141%, 24%, and 122%, respectively, and decreased malondialdehyde concentration by up to approximately 61% during the peak laying phase in laying hens (Johnson *et al.*, 2025). Moreover, it has been reported that rosemary extract rich in rosmarinic acid and carnosic acid increases plasma antioxidant activity and improves redox status in poultry under oxidative stress (Sierżant *et al.*, 2021). This demonstrates the close and reciprocal relationship between the antioxidant system and immune system. Increased oxidative stress leads to activation of inflammatory pathways and suppression of immune function, and increased antioxidant capacity may help to decrease inflammation and boost immune responses. Thus, phytobiotics with antioxidant and immunomodulatory activities have synergistic effects on the maintenance of physiological homeostasis of poultry. Additionally, several studies have demonstrated that phytogenic blends may exert stronger effects than single-compound supplementation due to synergistic interactions of bioactive compounds (Murwani *et al.*, 2024).

Immune Function of Phytobiotics

Phytobiotics have significant immunomodulatory effects in addition to their antioxidant activity. The immune system of poultry consists of a cellular and a humoral immune system, which work synergistically to combat pathogens. Phytobiotics are known to improve humoral immune responses through enhanced production of antibodies such as immunoglobulins IgA and IgG (Obianwuna *et al.*, 2024). Cinnamon, garlic, ginger, turmeric, green tea, and oregano are among the most widely known herbs for their immune-stimulating properties (Jimoh *et al.*, 2024; Simoni *et al.*, 2025; Johnson *et al.*, 2025). The biological effect of phytobiotics largely depends on the chemical composition of the phytobiotics and their specific plant source. These compounds may be administered either as whole plant extracts or in powdered forms, both of which preserve the therapeutic potential of the plant's active constituents. In poultry production systems, herbs have been shown to have biological impacts, including immune system modulation, which improves the birds' defensive mechanisms against infections and environmental stresses, and ultimately contributes to enhanced production and egg quality of laying hens (Darmawan *et al.*, 2022). Some phytobiotic plant sources, their main bioactive substances and their immunomodulatory effects in poultry are summarized in Table 1.

Supplementation of *Curcuma longa* extract has been reported to improve antibody production and immune organ development in broilers and enhance immune response against vaccination (Zhang *et al.*, 2018). Similar effects were observed with the supplementation of sweet orange peel extract, which increased immunoglobulin levels and improved immune responses through anti-inflammatory effects (Pourhossein *et al.*, 2019). Immune cell activity, such as B and T lymphocytes, macrophages, and natural killer (NK) cells, increases at the cellular level when exposed to phytobiotics. These mechanisms are largely mediated by regulating cytokine expression: inhibiting pro-inflammatory cytokines such as IL-1β, IL-6, and TNF-α and increasing anti-inflammatory cytokines such as IL-10, thereby maintaining immune balance (Evrendilek, 2026). This balanced cytokine response prevents excessive inflammation, inhibits tissue damage, and reduces the energy demands of the immune system. Consequently, more nutrients, including energy, are diverted to growth or egg production.

Phytobiotics can reduce chronic inflammation by suppressing these pro-inflammatory pathways and improving immune efficiency. Phytobiotics' immunomodulatory effects are linked to their impact on inflammatory signaling pathways such as mitogen-activated protein kinase (MAPK) pathways and nuclear factor kappa B (NF-κB), which regulate immune response and cellular stress (Meng *et al.*, 2021). The activation of NF-κB is one of the major mechanisms involved in inflammatory responses and induces pro-inflammatory gene expression. Phytobiotics such as thymol have been reported to inhibit NF-κB activation by preventing phosphorylation and degradation of IκBα, thereby preventing NF-κB translocation into the nucleus (Liu *et al.*, 2022).

Modulation of Intestinal Microflora by Phytobiotics

The intestinal microflora of poultry is a dynamic and complex microbial community dominated by bacteria from the phyla Firmicutes, Bacteroidetes, Proteobacteria, and Actinobacteria (Clavijo & Flórez, 2018; Al Hakeem *et al.*, 2023). Dominant microbial phyla, representative genera, and major functions in the poultry intestine are presented in Table 2. Under normal conditions, beneficial bacteria such as *Lactobacillus* and *Faecalibacterium* spp. predominate in the small intestine and are important for maintaining microbial balance and inhibiting pathogen colonization via competitive exclusion mechanisms (Naeem & Bourassa, 2025). Furthermore, bacteria such as *Bifidobacterium* and *Enterococcus* participate in fermentation and short-chain fatty acids (SCFAs) production, which are important for gut health (Wang *et al.*, 2025). However, disruption of microbial balance may increase the population of pathogenic microbes, thereby highly influencing poultry health and performance.

Phytobiotics, as plant-derived bioactive compounds, are a viable alternative for gut microbiota modulation by inhibiting pathogenic bacteria without impacting beneficial microorganisms and improving intestinal mucosal integrity (Darmawan *et al.*, 2022). They can improve gastrointestinal health and poultry performance through several mechanisms, such as inhibiting the growth of pathogenic bacteria, disrupting microbial cell membranes, and interfering with microbial enzymatic systems (Darmawan *et al.*, 2022; Rachwał & Gustaw, 2025).

Studies have reported that *Moringa oleifera* leaves, *Carica papaya* leaves, *Anredera cordifolia* leaves, and *Centella asiatica* leaves possess significant potential as natural phytobiotics (Song *et al.*, 2024; Rusli *et al.*, 2025**;** Akhter *et al.*, 2021). Their bioactive compounds, including polyphenols, flavonoids, saponins, alkaloids, triterpenoids, and papain, are known to inhibit the growth of pathogenic bacteria and improve the health and immune system of poultry. These bioactive compounds inhibit bacteria through complex mechanisms at the cellular and molecular levels. Thymol and carvacrol impact the integrity of bacterial cell membranes through interactions with the phospholipid bilayer, increasing membrane permeability and leading to leakage of ions and other cytoplasmic components (Moghrovyan and Sahakyan,

Table 1. Some phytobiotic plant sources, their main bioactive compounds and their immunomodulatory effects in poultry

Immunomodulatory mechanisms	Plant sources	Major bioactive compounds	Immune effects	References
Enhancement of humoral immunity	Curcuma longa, sweet orange peel	Curcumin, flavonoids	↑ Antibody production, ↑ IgA, ↑ IgG, enhanced vaccine-induced immune response	Obianwuna *et al*., 2024; Zhang *et al*., 2018; Pourhossein *et al*., 2019
Activation of cellular immunity	Cinnamon, garlic, ginger, turmeric, green tea, oregano	Polyphenols, flavonoids, thymol, carvacrol, curcumin, allicin	↑ B lymphocytes, ↑ T lymphocytes, ↑ macrophages, ↑ NK cells	Jimoh *et al*., 2024; Simoni *et al*., 2025; Johnson *et al*., 2025
Regulation of cytokine production	Thyme, oregano, turmeric	Thymol, carvacrol, curcumin	↓ IL-1β, ↓ IL-6, ↓ TNF-α, ↑ IL-10, maintenance of immune homeostasis	Evrendilek, 2026; Liu *et al*., 2022
Modulation of inflammatory signaling pathways	Thyme, turmeric	Thymol, curcumin	Inhibition of NF-κB activation and modulation of MAPK signaling, reducing chronic inflammation	Meng *et al*., 2021; Liu *et al*., 2022
Antioxidant-mediated immune protection	Green tea, bamboo leaves, rosemary	Catechins, polyphenols, rosmarinic acid, carnosic acid	Activation of Nrf2 pathway, ↑ SOD, GPx, CAT, protection against oxidative stress-induced immune dysfunction	Kikusato, 2021; Shen *et al*., 2019; Simoni *et al*., 2025

Table 2. Dominant microbial phyla, representative genera, and major functional in the poultry intestine (Clavijo & Flórez, 2018; Al Hakeem *et al*., 2023)

Phylum	Representative genera	Main functions
Firmicutes	*Lactobacillus, Faecalibacterium, Enterococcus, Eliobacterium, Oscillibacter, Peptococcus, Oscillospira, Clostridium, and Eubacterium.*	Contributes to competitive exclusion of pathogens and enhances protease activity, trypsin activity, and lipase activity; increases SCFA production; and supports intestinal barrier integrity and gut health
Bacteroidetes	*Bacteroides*	Enhances degradation of complex carbohydrates and maintenance of gut microbial homeostasis
Proteobacteria	*Escherichia, Shigella, Neisseria*	Contains mostly Gram-negative bacteria. Although they are usually present in low abundance, excessive growth is associated with intestinal dysbiosis and compromised poultry health
Actinobacteria	*Bifidobacterium*	Beneficial bacteria that increase the activities of protease, trypsin, and lipase, participate in fermentation and the production of SCFA, and contribute to intestinal microbial balance and gut health

2024). Flavonoids may affect bacterial gene expression by disrupting DNA/RNA replication and transcription, leading to bacterial death. Moreover, flavonoids inhibit protein synthesis or block the function of some enzymes to kill pathogenic bacteria, thus interfering with the processes of protein synthesis and modification, ultimately resulting in bacterial death (Zhang *et al.,* 2025).

Bioactive compounds also interfere with biofilm formation and quorum sensing systems in pathogenic bacteria, which are key factors in microbial resistance against antibiotics and extreme environmental conditions (Samrot *et al.,* 2021). Flavonoids, eugenol, and carvacrol can disrupt the generation of signaling molecules, thereby reducing virulence gene expression and bacterial colonization of host tissues. Naringin can induce oxidative stress by forming ROS, destroying microbial proteins, lipids, and DNA (Han and Lee, 2022). Additionally, saponins, capsaicin, flavonoids, catechins, and quercetin promote the growth of beneficial bacteria, such as *Lactobacillus* and *Bifidobacterium*, thereby enhancing short-chain fatty acid (SCFA) production, especially acetate, propionate, and butyrate. These metabolites serve as an energy source for intestinal epithelial cells and strengthen the integrity of the intestinal barrier, maintain immune homeostasis, and lower intestinal pH, creating an unfavorable environment for pathogenic bacteria (Singh *et al.,* 2025; Wang *et al.,* 2025).

Morphological Aspects and Intestinal Barrier Function of Phytobiotics

The relationship between intestinal barrier and intestinal morphology in poultry is important, as both are key factors in the maintenance of gastrointestinal health, nutrient absorption efficiency, and production performance. The intestinal barrier consists of the mucus layer, gut microbiota, intestinal epithelial cells, mucosal immune system, and tight junction proteins, which work together to protect the gastrointestinal tract from pathogenic bacterial infection, toxins, and harmful antigens, and to modulate intestinal permeability (Song *et al.,* 2024; Proszkowiec-Weglarz *et al.,* 2020). Positive effects of phytobiotics on intestinal morphology in poultry are presented in Table 3. Proper intestinal barrier integrity maintains the structure of the intestinal mucosa and thus allows for optimal digestion and nutrient absorption. Generally, intestinal health in poultry is associated with positive intestinal morphology (optimal villus height, normal crypt depth, and a high villus height-to-crypt depth ratio (VH/CD ratio). Higher villi represent a larger absorptive surface area, leading to increased nutrient absorption capacity, while shallow crypts indicate less tissue damage and more efficient enterocyte regeneration (Belote *et al.,* 2023). Conversely, destruction of the intestinal barrier may result in epithelial damage, villus atrophy, crypt hyperplasia, and damage to tight junction proteins, which can increase intestinal permeability and lead to the translocation of pathogenic bacteria and endotoxins into intestinal tissues. These conditions lead to mucosal inflammation, increased oxidative stress, decreased nutrient absorption efficiency, and ultimately impact growth performance in poultry (Sharma & Kim, 2024). Therefore, intestinal morphological parameters (villus height, villus surface area, crypt depth, and VH/CD ratio) are commonly used as primary indicators to assess intestinal barrier integrity and gastrointestinal physiological status in poultry.

In recent years, phytobiotics have been widely used as natural alternatives to AGPs for the enhancement of

Table 3. Positive effects of phytobiotics on intestinal morphology in poultry

Phytobiotic sources	Optimum dosage	Observed effects	References
Mixed essential oils, saponins, and tannins	500 mg/kg diet	Improving villus height and the VH/CD ratio and reducing crypt depth in the duodenum, jejunum, and ileum of broiler chickens	Galamatis *et al*. (2025)
Curcumin	300 mg/kg diet	Increasing villus height, VH/CD ratio, and intestinal barrier integrity and reducing crypt depth in the jejunum of laying hens	Xu *et al*. (2024)
Morinda citrifolia extract	16.3 mg/kg BW	Increasing villus height and VH/CD ratio in the duodenum, jejunum, and ileum of broiler chickens	Paredes-López *et al.* (2026)
Ginger extract	0.1% diet	Increasing villus height and VH/CD ratio in the jejunum of broiler chickens	Yang *et al*. (2026)
Spirogyra jaoensis extract	0.5% diet	Increasing villus height, VH/CD ratio, and goblet cell area of laying hens	Ramadhanti *et al*. (2021)
Moringa oleifera leaf powder	1.2% diet	Increasing the small intestine's length and the villi surface area of the duodenum and enhancing the microarchitecture and mucin production of broiler chicken	Khan *et al*. (2017)
Flavonoid of Neohesperidin dihydrochalcone	100 mg/kg diet	Improving villous height and VH/CD ratio and decreasing ileum crypt depth of laying hens	Zhu *et al*. (2021)
Curcuma aeruginosa powder	1% diet	Decreasing crypt depth and intestinal inflammation of quail	Murwani *et al*. (2024)
Chestnut burs and flower	0.1 % as powder and 0.015% as extract in diet	Enhancing villi surface area, villi height, and VH/CD ratio in the duodenum of broiler chickens	Ozturk *et al*. (2026)

intestinal health in poultry. The action of phytobiotics is related to different bioactive compounds of plant origin with antimicrobial, anti-inflammatory, and antioxidant activities, which help maintain intestinal barrier integrity and improve intestinal morphology. Phytobiotics have been shown to inhibit the production of pro-inflammatory cytokines such as IL-6 and TNF-α, which are related to epithelial damage and increased intestinal permeability, thereby suppressing inflammatory responses (Evrendilek, 2026). The reduction of inflammation helps preserve mucosal integrity, maintain villus structure, and minimize enterocyte damage. Furthermore, phytobiotics have a potent antimicrobial effect on pathogenic bacteria and enhances intestinal microbial balance by increasing the number of beneficial bacteria (Darmawan *et al.*, 2022; Singh *et al.*, 2025). A stable microbiota is important to maintain a healthier intestinal environment and proper epithelial regeneration. Recent studies suggest that allicin and curcumin can upregulate tight junction protein expression such as occludin and claudin, thus enhancing intestinal barrier integrity, decreasing intestinal permeability, and preventing mucosal damage (Gao *et al.*, 2022). Curcumin has been shown to upregulate tight junction protein expression, including occludin and zonula occludens-1 (ZO-1), thereby strengthening the intercellular junctions of epithelial cells and reducing intestinal permeability. Moreover, curcumin prevents oxidative damage to intestinal epithelial cells by inhibiting the NF-κB inflammatory pathway and activating the Nrf2 antioxidant signaling pathway (Xu *et al.*, 2024; Wu *et al.*, 2022). Nrf2 activation increases the production of endogenous antioxidant enzymes to protect enterocytes from damage due to free radicals. Inhibition of NF-κB suppresses inflammatory responses that may damage the intestinal mucosal tissues (Wu *et al.*, 2022). Collectively, these antioxidant and anti-inflammatory mechanisms preserve epithelial integrity, promote enterocyte regeneration, and maintain villus architecture and height, thus improving intestinal morphology and absorptive function.

The supplementation of phytobiotics has been shown to increase the villus height of the duodenum, jejunum, and ileum and to improve the VH/CD ratio, which is an indication of an improvement in nutrient absorptive capacity and intestinal health in studies on broiler chickens (Galamatis *et al.*, 2025; Ozturk *et al.*, 2026). Similar improvements in villus height and VH/CD ratio have also been reported in Pekin ducks (Hu et *al.*, 2025), quails (Mahmoud *et al.*, 2025), and laying hens (Xu *et al.*, 2024). Meanwhile, flavonoids, quercetin, and catechins show beneficial effects by enhancing local antioxidant activity, alleviating mucosal inflammation, and modulating the gut microbiota composition, thereby increasing the production of beneficial metabolites such as SCFAs (Singh *et al*., 2025). SCFAs, especially butyrate, help maintain the integrity of the mucosa and the structure of the villi by tightening the tight junctions (Mathewson *et al.*, 2016). These effects improve intestinal morphology as reflected by increased villus height, decreased crypt depth, and increased VH/CD ratio. This indicates lower mucosal damage and more energy allocated to growth and nutrient absorption instead of tissue repair (Sharma and Kim, 2024). Additionally, flavonoids have been reported to enhance mucus production by stimulating goblet cell activity and enhancing mucin genes such as MUC2 (Damiano *et al.*, 2018). The increased thickness of the mucus layer protects the villus surface from pathogenic invasion and toxins, thus reducing epithelial injury and enhancing the efficiency of nutrient absorption (Proszkowiec-Weglarz *et al.*, 2020).

Application and Efficacy of Phytobiotics on Poultry Performance

Numerous studies have reported that plant extracts or powders such as ginger, turmeric, garlic, noni leaves, moringa leaves, and mangosteen peel serve as a source of phytobiotics and result in better poultry performance (Table 4). For instance, the use of 0.6% turmeric powder improved the health status of ducks, indicating an increase in the number of erythrocytes, hematocrit, hemoglobin concentration, and the percentage of total lymphocytes (Nova & Yellita, 2015). Meanwhile, the combined supplementation of 1% mangosteen peel meal and 1% turmeric meal in a duck diet has been proven to be more effective in increasing body weight and reducing mortality compared to single administration (Kusmayadi *et al.*, 2019). The content of curcumin in turmeric and xanthones in mangosteen peel may synergize in improving digestive tract health by balancing the microflora population through their antimicrobial properties. Curcumin and xanthones are also antioxidant compounds that can protect enzymes from free radical damage, increasing their secretion and function in the poultry digestive system (Zhang *et al.*, 2018; Zhang *et al.*, 2015; Kusmayadi *et al.*, 2019). Thus, it can maximize digestibility and nutrient absorption to increase body weight. Another study using 2.5% to 10% *Moringa oleifera* leaf meal in a laying hen diet accelerated follicle number and egg production (Shen *et al.*, 2022). This positive effect is due to the main phenolic content in *Moringa oleifera* leaves, namely kaempferol, quercetin, myricetin, chlorogenic acid, gallic acid, luteolin, and rutin (Prabakaran *et al.*, 2018; Yulianto *et al.*, 2024). The antioxidant properties of quercetin and kaempferol in *Moringa oleifera* leaf can inhibit ROS formation during follicle formation, prevent fatty peroxides, which are precursors of egg yolk formation, and protect egg yolk transport from the liver to the ovaries (Kusmayadi *et al.*, 2019; Prabakaran *et al.*, 2018). Additionally, the addition of a 11 mg/kg body weight fruit leaf (*Morinda citrifolia L.)* extract enhanced broiler performance, *Lactobacillus bacteria*, and villous height (Paredes-López *et al.*, 2026). However, Ismoyowati *et al.* (2019) reported that supplementation of garlic, turmeric, and ginger (3% each) in the diet of ducks did not affect body weight gain, feed intake, and feed efficiency but yielded a higher percentage of the carcass.

Although phytobiotics have shown potential effects on poultry health and production performance, the processing methods, storage conditions, and handling practices affecting the stability of bioactive compounds have a great influence on their biological efficiency. The common application of plant herbs is by drying

Table 4. The positive effects of phytobiotic applications on poultry performances

Phytobiotic sources	Species	Bioactive compounds	Observed effects	Optimum dose	Inclusion methods	References
Zingiber officinale var. rubrum extract	broiler	diterpenes, monoterpenes, vanilloids, sesquiterpenes, flavonoids	Increasing performance, meat quality, and intestinal health	0.10%	feed	Yang *et al*. (2026)
Moringa oleifera L leaf meal	duck	quercetin, myricetin, kaempferol, gallic acid, chlorogenic acid, alkaloids	Increasing body weight gain	1%	feed	Trisnadewi *et al*. (2020)
			Increasing follicle number and egg production of laying hens	2.50%	feed	Shen *et al*. (2022)
Morinda citrifolia leaf extract	broiler	flavonoids, polyphenols, tannins, triterpenes, and steroids	Increasing performance and intestinal health	11.0 mg/kg body weight	feed	Paredes-López *et al*. (2026).
Artocarpus heterophyllus leaf extract		quercetin, kaempferol, catechin, artocarpin	Enhancing meat quality and modulating gut microbiota improves consumer acceptability without adversely affecting growth performance.	5 mL/L	Drinking water	Safiyu *et al*. (2026)
Garlic (*Allium sativum* L) + Turmeric (*Curcuma domestica*) meal	laying hen	allicin, alliin, diallyl, S-allyl-cysteine turmeric: curcumin, demethoxycurcumin, bisdemethoxycurcumin, essential oil, flavonoids, tannins	Increasing egg production and egg weight	0.1% garlic + 0.1% turmeric	feed	Pradipta *et al*. (2019)
Garcinia mangostana L. peel + Turmeric (*Curcuma domestica* Val) extract	duck	xanthones, anthocyanins, phenolic acids, tannins	Increasing live body weight and daily body weight gain	1% mangosteen peel + 1% turmeric	drinking water	Kusmayadi *et al*. (2019)
Andrographis paniculata leaf meal	duck	andrographolide, deoxyandrographolide, neoandrographolide	Increasing egg production and feed efficiency	0.40%	feed	Yulianti *et al.* (2015)
Olea europaea leaf extract	broiler	hydroxytyrosol, vanillin, rutin, caffeic acid, catechin	Enhancing performance and beneficial microbes in cecal	600 mg kg^{-1}	feed	Erener *et al*. (2020)
Mentha piperita	laying hen	menthol, menthone, menthyl acetate	Enhancing feed efficiency and yolk color	200 mg kg^{-1}	feed	Rahman *et al*. (2021)
Chestnut flower and burs	broiler	xanthones, flavonoids, benzophenones, phenolic acids	Enhancing growth, villous surface area, and intestinal Lactobacillus population	0.1% chestnut powder; 0.015% chestnut extract	feed	Ozturk *et al.* (2026)
Camellia sinensis (L.) O. Ktze extract	laying hen	theanine, theobromine, caffeine, catechins	Enhancing the egg yolk lipid composition without altering egg production	300 mg kg^{-1}	feed	Huang *et al*. (2019)
Eleutherine palmifolia meal	quail	flavonoid, alkaloid, tannin, steroid, triterpenoid, phenol, saponin	Reducing egg cholesterol	0.30%	feed	Haerul *et al*. (2024)

and flouring the plant parts with optimal drying temperatures for preserving vitamin C, flavonoids, polyphenols, glycosides, volatile compounds, and antioxidant activity being 50-60 °C, 60-70 °C, 55-60 °C, 45-50 °C, 40-50 °C, and 50-70 °C, respectively (El Gamal *et al*., 2023). The decrease in total polyphenolic bioactive compounds in dry products can be caused by chemical decomposition due to oxidation during processing and storage, thus decreasing the antioxidant and antimicrobial activities of phytobiotics and reducing their biological effects in poultry. In fact, thermal treatment at the right temperature can result in the rupture of plant cell walls, which further increases the extraction process of phenolic compounds. Heating extracts of plant bioactive compounds at 50 °C increased phenolic compound content and antioxidant activity but decreased vitamin C content due to its thermolabile nature, which is easily oxidized by heating (Cunha *et al*., 2021). Meanwhile, Sharmin *et al.* (2016) reported that extraction at temperatures above 40 °C for more than 40 minutes degraded polyphenolic compounds and flavonoids, thereby reducing their yield. Therefore, optimizing extraction temperature and processing time is an important step in herbal technology, as it aims to maximize the recovery of phytochemicals while minimizing thermal degradation. Storage for 50 days has a significant effect on decreasing bioactive compound yield and antioxidant activity (Tobal *et al*., 2019). The decrease in anthocyanins, one of the flavonoid compounds, also fell to 44% after 21 days of storage at 30 °C (Alves *et al*., 2017). Tummanichanont *et al.* (2018) also found that the total phenolic content of dried *Andrographis paniculata* leaves stored at 25 and 35 °C for 6 months decreased by 50.92% and 56.32%, respectively. Similarly, DPPH values decreased by 19.96% and 23.77%, respectively. Therefore, suitable drying and storage conditions, including temperature control, protection from light and oxygen, and airtight packaging, are important for minimizing the degradation of bioactive compounds. In addition, encapsulation is another effective approach to protect highly sensitive bioactive compounds from degradation and to enhance their stability during storage.

Additionally, the processing and storage stability and the practical efficacy of phytobiotics in chicken production are also closely associated with the implementation of proper farm biosecurity procedures. Good biosecurity management promotes poultry health, reduces pathogen exposure, and enhances the efficacy of phytobiotics in maintaining poultry performance and reducing disease cases. The strict application of biosecurity correlates negatively with bacterial resistance in animals, enhances animal health, and decreases the need for antimicrobial use (Raasch *et al.*, 2018). According to Pinto *et al.* (2020), good biosecurity includes bio-containment, bio-exclusion, and bio-management. Bio-containment prevents the spread of pathogenic bacteria or diseases to other farms through cleaning and disinfecting the farm. Bio-exclusion prevents exposure to new pathogens by requiring showering and monitoring health status before entering the farm, controlling vehicles, and restricting the movement of people and animals within the farm. Meanwhile, bio-management controls and manages pathogens that already exist on the farm, such as using all-in-all-out systems.

CONCLUSION

Phytobiotics have great potential as natural alternatives to antibiotic growth promoters in poultry production by enhancing gut health, antioxidant status, immune function, nutrient utilization, and overall production performance. However, the efficacy of bioactive compounds depends on their stability and bioavailability, which are influenced by processing, storage, and application procedures. Therefore, standardization of phytobiotic preparation and proper handling are important for uniform biological responses under commercial production conditions. Further research should focus on optimizing feed dosages depending on the source of the phytobiotic, conducting large-scale studies across different poultry species and production systems to confirm efficacy, and elucidating the molecular mechanisms underlying the biological effects of phytobiotics. These developments will contribute to the development of standardized evidence-based phytobiotic applications for sustainable poultry production.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

We declare the use of generative AI and AI-assisted technologies for language improvement, figure design, and reference organization. All content has been reviewed and edited to reflect the understanding, interpretation, and academic integrity.

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