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Phytochemical Modulation of Host Immunity for the Control of Avian Coccidiosis

Meruva Nageswara SKP*
*Undergraduate Student, Rajiv Gandhi Institute of Veterinary Education and Research, Pondicherry University.
***Corresponding author**: pranavmeruva@gmail.com
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Abstract

Avian coccidiosis, caused by multiple *Eimeria* sp., remains one of the most economically damaging enteric diseases of poultry worldwide. Despite the long-standing reliance on anticoccidial drugs and live vaccines, the sustainability of conventional control strategies is increasingly compromised by drug resistance, regulatory restrictions, and shifts toward antibiotic-free production systems (Bera *et al*., 2010 and McDougald, 2003). This review critically examines phytochemicals as host-directed alternatives for coccidiosis control, emphasizing their immunomodulatory, antioxidant, anti-inflammatory, and gut-protective mechanisms. Evidence from in vitro studies, controlled experimental trials, and emerging field data indicates that phytogenic compounds, including polyphenols, essential oils, saponins, and curcuminoids can mitigate intestinal pathology, enhance mucosal immunity, and reduce performance losses associated with both clinical and subclinical infections (Park *et al*., 2023 and Yadav *et al*., 2020). Particular attention is given to the relevance of phytochemical interventions within Indian poultry production systems, where disease pressure, climatic factors, and consumer demand converge to necessitate sustainable solutions.

Keywords: Eimeria, Coccidiosis, Phytochemicals, Immunomodulation, Gut Health.

Introduction

The poultry sector is among the fastest-growing components of global animal agriculture, contributing substantially to protein security and rural livelihoods. In India, intensified poultry production has amplified the impact of infectious diseases, with avian coccidiosis consistently ranked among the most economically significant constraints to productivity (Pant *et al*., 2019). The disease is caused by obligate intracellular protozoa of the genus Eimeria, which induce varying degrees of intestinal epithelial destruction, inflammation, and nutrient malabsorption (McDougald, 2003).

Globally, the economic burden of coccidiosis is profound, with annual losses estimated to exceed USD 14 -15 billion (Bera *et al*., 2010). Importantly, only a minority of

these losses arise from overt clinical outbreaks. The majority are attributable to subclinical infections that impair feed efficiency, weight gain, and flock uniformity without obvious clinical signs (McDougald., 2003). This hidden nature of loss has led to coccidiosis being described as an "embezzler" rather than a "thief," emphasizing its chronic and cumulative impact on production efficiency.

Limitations of Conventional Coccidiosis Control Strategies

Chemical and Ionophore anticoccidials have long constituted the cornerstone of coccidiosis prevention in poultry production. Although these compounds were initially highly effective, their prolonged and often uninterrupted use has led to extensive resistance development among *Eimeria* populations, resulting in declining efficacy across commercial systems (Bera *et al*., 2010). Evidence from both Indian and international studies suggests resistance to most commonly employed coccidiostats, while opportunities for novel drug development remain limited due to residue-related concerns and increasingly stringent regulatory frameworks (Jadhav., 2024).

Live oocyst vaccines represent a biologically rational alternative through the induction of species-specific immunity. However, their widespread adoption is limited by high cost, labour intensive application, reliance on efficient litter recycling, and the potential for vaccine-associated intestinal stress or impaired nutrient absorption (McDougald., 2003). These limitations are further amplified by the growing adoption of cage-free and litter-based housing systems, which enhance environmental exposure to sporulated oocysts. Concurrently, national and global shifts toward antibiotic-free poultry production have curtailed prophylactic antimicrobial use, underscoring the need for complementary and sustainable control approaches (Park *et al*., 2023).

Rationale for Phytochemical-Based Interventions

Contemporary coccidiosis management is increasingly moving away from a parasite centered approach toward a host-directed strategy that prioritizes intestinal resilience and disease tolerance. Conventional anticoccidials primarily target discrete stages of the *Eimeria* life cycle, thereby exerting strong selective pressure that accelerates resistance development (Bera *et al*., 2010). In contrast, phytochemicals exert pleiotropic effects on host immune responses, epithelial integrity, oxidative homeostasis, and gut microbial balance, reducing dependence on direct anti-parasitic activity (Park *et al*., 2023).

This host-oriented framework is particularly applicable to coccidiosis, where disease severity is influenced not only by parasite burden but also by exaggerated inflammatory and oxidative host responses. Through modulation of these pathways, phytochemicals help

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minimize tissue damage, sustain nutrient absorption, and maintain productive performance despite controlled parasitic exposure. Accumulating evidence supports their ability to reduce lesion severity, oocyst shedding, and production losses, particularly under subclinical challenge scenarios (Bera *et al*., 2010 and Park *et al*., 2023).

Immunomodulatory and Gut-Protective Mechanisms of Phytochemicals

1) Anti-inflammatory effects

Infection with Eimeria spp. triggers marked upregulation of pro-inflammatory cytokines, including interleukin-1β and interleukin-8, which contributes to mucosal injury. Bioactive compounds such as cinnamaldehyde, thymol, carvacrol, and polyphenols derived from pomegranate have been shown to suppress these inflammatory mediators, thereby mitigating intestinal inflammation and preserving mucosal structure (Park *et al*., 2023).

2) Antioxidant activity

Oxidative stress plays a central role in the pathogenesis of coccidiosis. Curcumin, the primary bioactive constituent of turmeric (*Curcuma longa*), enhances antioxidant capacity by elevating glutathione concentrations and stimulating antioxidant enzyme systems, leading to reductions in lesion severity and oocyst excretion in experimentally challenged broilers (Yadav *et al.,* 2020).

3) Enhancement of intestinal barrier integrity

Coccidial infection disrupts tight junction proteins, compromising epithelial barrier function and facilitating secondary bacterial translocation. Polyphenolic compounds from green tea (*Camellia sinensis*) have been shown to upregulate tight junction proteins such as occludin, thereby reinforcing epithelial integrity and decreasing intestinal permeability (Jelveh *et al*., 2022).

4) Modulation of gut microbiota

Beyond host tissue effects, phytochemicals influence intestinal microbial ecology by selectively promoting beneficial bacteria, particularly *Lactobacillus* sp., while suppressing opportunistic pathogens. Essential oil combinations derived from oregano and citrus species have demonstrated favourable shifts in gut microbiota composition alongside measurable reductions in oocyst shedding (Gordillo-Jaramillo *et al*., 2021).

5) Direct anti-parasitic effects

Some phytochemicals exert direct anticoccidial actions. Saponins compromise parasite membrane integrity, tannins interfere with oocyst wall structure and sporulation processes, and pomegranate extracts have been reported to reduce *E. tenella* sporozoite viability under in vitro conditions (Pop *et al*., 2019).

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Evidence from Experimental and Applied Studies

Supplementation of broiler diets with green tea powder at inclusion levels ranging from 0.1 to 0.8 g/kg feed has been associated with improved body weight gain, feed conversion efficiency, and intestinal morphology in birds challenged with mixed *Eimeria* infections, with optimal doses approaching the efficacy of conventional coccidiostats (Jelveh *et al*., 2022). Similarly, curcumin supplementation at approximately 200 mg/kg feed significantly lowers lesion scores and faecal oocyst output while enhancing systemic antioxidant status (Yadav *et al*., 2020). Essential oil formulations derived from oregano, thyme, and citrus species have consistently demonstrated reductions in intestinal inflammation and oocyst shedding, in some instances surpassing the performance of amprolium under controlled experimental conditions (Gordillo-Jaramillo *et al*., 2021 and Lahlou *et al*., 2025). Polyherbal preparations are particularly promising due to their ability to address the multispecies complexity of *Eimeria* infections (Pop *et al*., 2019).

Relevance to Indian Poultry Production Systems

Within India, the adoption of phytochemicals is accelerating in response to escalating anticoccidial resistance, growing consumer preference for antibiotic-free poultry products, and heightened emphasis on food safety (Pant *et al.*, 2019 and Jadhav., 2024). Indigenous medicinal plants such as neem (*Azadirachta indica*), garlic (*Allium sativum*), turmeric, and *Tinospora cordifolia* are widely incorporated into both commercial feed additives and traditional farm-level practices. Optimal efficacy is achieved when phytochemicals are integrated with vaccination programs, litter management, and biosecurity measures rather than used in isolation.

Future Directions and Research Priorities

The practical application of phytochemicals is constrained by variability in plant origin, extraction techniques, and concentrations of active constituents. Moreover, several compounds, including curcumin, exhibit limited bioavailability due to rapid metabolism and poor intestinal absorption (Yadav *et al*., 2020). Advances in formulation technologies, such as microencapsulation and nano-delivery systems, offer promising avenues to enhance stability, intestinal uptake, and protection of volatile compounds during feed processing (Park *et al*., 2023). Well-designed long-term field studies and standardized dosing guidelines remain essential research priorities.

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Conclusion

Host directed modulation through phytochemicals represents a scientifically credible and increasingly feasible approach for the control of avian coccidiosis. By mitigating inflammatory and oxidative damage, preserving epithelial integrity, and favourably shaping the gut microbiome, phytogenic additives address the multifaceted nature of coccidial disease rather than focusing exclusively on parasite elimination. As the poultry industry continues to face rising drug resistance and growing pressure for antibiotic-free production, phytochemicals are well positioned to become integral components of sustainable, integrated coccidiosis control strategies.

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