
MODE OF ACTION OF HERBAL BIOACTIVE COMPOUNDS SAPONINS AND POLYPHENOLS AGAINST *EIMERIA* SPP. INFECTION IN BROILER CHICKENS: A REVIEW**Mekanisme Kerja Senyawa Bioaktif Herbal Saponin dan Polifenol dalam Mengendalikan Infeksi *Eimeria* spp. pada Ayam Broiler: Sebuah Tinjauan****Onisa Inggita Putri*, Hendi Setiyatwan, Ujang Hidayat Tanuwiria, Mansyur**

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Abstract

Coccidiosis, caused by *Eimeria* spp., remains a major parasitic challenge in the global poultry industry, leading to significant economic losses due to impaired performance and high mortality rates in poultry. Although synthetic chemoprophylaxis has long been the standard, escalating drug resistance and market demand for chemical-free residues necessitate the development of sustainable alternative strategies to control these parasites. This review critically evaluates the potential integration of phytochemical bioactive compounds, specifically saponins and polyphenols, as future anticoccidial agents. Saponins are amphiphilic glycosides that selectively bind to cholesterol in the *Eimeria* spp. cell membrane, inducing cellular lysis and interrupting various stages of the parasite's life cycle. Conversely, polyphenols mediate structural damage to the cell walls of sporozoites, which are the most pathogenic stage of coccidia infection. This study synthesizes data on the synergistic modes of action of these two compounds, where the combination of saponin-based membrane destruction and polyphenol-driven cell wall penetration offers comprehensive intestinal protection. By providing a profound understanding of these molecular mechanisms of action, this review aims to establish a robust scientific foundation for developing environmentally friendly, effective, and applicable herbal-based mitigation strategies for the modern poultry industry.

Keywords: anticoccidials, *Eimeria* spp., polyphenols, saponins**Abstrak**

Koksidiosis yang diakibatkan oleh *Eimeria* spp. tetap menjadi tantangan parasiter utama dalam industri perunggasan global karena memicu kerugian ekonomi yang signifikan akibat penurunan performa dan tingginya mortalitas. Meskipun kemoprofilaksis sintetik telah lama digunakan, eskalasi resistensi obat dan desakan pasar terhadap residu kimia menuntut adanya

strategi alternatif yang berkelanjutan. Artikel tinjauan ini secara kritis mengulas potensi integrasi senyawa bioaktif fitogenik, khususnya saponin dan polifenol, sebagai agen antikoksidosis masa depan. Saponin merupakan glikosida amfifilik yang secara selektif berikatan dengan kolesterol membran *Eimeria* spp., sehingga menginduksi lisis seluler dan menginterupsi berbagai fase siklus hidup parasit. Di sisi lain, polifenol memediasi kerusakan struktural pada dinding sel sporozoit, yang merupakan fase paling patogenik dalam infeksi koksidia. Kajian ini mensintesis data mengenai sinergisme mekanisme kerja kedua senyawa tersebut, di mana kombinasi destruksi membran berbasis saponin dan penetrasi dinding sel oleh polifenol menawarkan proteksi usus yang komprehensif. Melalui pemahaman mendalam mengenai mekanisme aksi molekuler ini, artikel ini diharapkan dapat memberikan landasan ilmiah yang kuat dalam pengembangan strategi mitigasi koksidosis berbasis herbal yang ramah lingkungan, efektif, dan aplikatif pada industri perunggasan modern.

Keywords: antikoksidia, *Eimeria* spp., polifenol, saponin

INTRODUCTION

Coccidiosis in poultry is caused by the intracellular protozoan *Eimeria* spp., which belong to the phylum Apicomplexa. This disease is estimated to cause global economic losses in the poultry industry, primarily due to reduced production performance and commercial losses. To date, coccidiosis control has generally been performed using chemotherapeutic agents (Cejas *et al.*, 2011). Current prevention and control strategies involve the use of chemical coccidiostats and ionophores in poultry. However, drug resistance remains a significant limitation. Multidrug resistance and cross-resistance can reduce the effectiveness of anticoccidial drugs (Clarke *et al.*, 2014). The ban on the use of anticoccidial agents as feed additives is likely a major driver of the growing research on the active compounds in herbal products (Han *et al.*, 2022). Therefore, a new, more effective, and sustainable approach is needed to control the disease.

Globally, the modern poultry industry is under strict regulatory pressure regarding food safety and campaigns to restrict the use of synthetic chemical drugs (antibiotic growth promoter-free). However, the adoption of high-stock-density rearing systems for economic efficiency has exponentially increased the risk of coccidiosis transmission through litter contamination with *Eimeria* spp. oocysts. in the litter. Decades of reliance on the preventive and monotonous use of synthetic coccidiostats have triggered a widespread escalation of multidrug resistance in parasites, treatment failures in the field, soaring production costs, and an increased risk of chemical residues in chicken meat that threaten consumer health. Therefore, the discovery of alternative, environmentally friendly anticoccidial agents has become a core strategy for maintaining gut health and feed conversion ratio (FCR) efficiency, where groups of herbal compounds, such as saponins derived from *Yucca schidigera* and polyphenols, are potential solutions with promising anticoccidial efficacy (Benarbia *et al.*, 2022; El-Shall *et al.*, 2021).

Saponins function as amphiphilic glycosides that selectively bind to cholesterol within the cell membranes of *Eimeria* spp. to induce cellular lysis and disrupt multiple phases of the parasite's life cycle (Cheeke, 2000). Polyphenols mediate structural damage to the sporozoite cell wall while concurrently reinforcing the intestinal mucosal barrier, attenuating oxidative stress, and suppressing the proliferation of secondary pathogens (Abdel-Moneim *et al.*, 2020; Remmal *et al.*, 2021). This multitarget mechanism, encompassing the physical membrane destruction exerted by saponins and the host cell defense potentiation conferred by polyphenols, renders *Eimeria* spp. considerably less capable of developing resistance against these compounds. This synergistic potential underpins the significance of the present literature review in establishing a robust scientific foundation for the development of phyto-genic-based coccidiosis mitigation strategies in the poultry industry.

Based on the aforementioned background, this article comprehensively reviews and critically examines the mechanisms of action of saponin and polyphenol compounds in inhibiting and disrupting the life cycle of protozoa responsible for coccidiosis.

RESEARCH METHODS

Research Object

The objects utilized in this study were secondary scientific journal articles, comprising both original research and review articles. The literature was obtained through comprehensive searches of reputable scientific databases, including Scopus, ScienceDirect, PubMed, and e-Resources Perpustakaan. The literature sample boundaries were controlled using the following criteria:

Inclusion Criteria: Original scientific journal articles and review articles published between 2000 and 2025, addressing the molecular mechanisms of action of saponin and polyphenol active compounds (derived from both purified extracts such as *Yucca schidigera* and herbal products), and presenting applicative data in broiler chickens with *Eimeria* spp. parasite challenge tests.

Exclusion Criteria: Scientific articles that did not provide full-text access, conference proceeding abstracts, phytochemical research outside the saponin and polyphenol groups in isolation (such as organic acids or pure essential oils), and studies on the herbal application of coccidiosis in non-poultry livestock commodities.

Research Design

This study was designed using an observational method and a descriptive-analytical literature review approach. This study comprehensively examined the available literature objectively without conducting independent laboratory trials or experimental treatments.

Research Variables

The variables observed and analyzed in this literature review encompass the following: Independent variables: Type of phytochemical bioactive compound (saponins and polyphenols) and their preparation forms (pure plant extracts or herbal product formulations). Dependent variables: anticoccidial efficacy parameters in broiler chickens, including growth performance (feed conversion ratio/FCR), intestinal health management systems (jejunal histomorphology), and oocyst excretion levels (oocysts per gram/OPG). Control variables: publication timeframe of the articles (2000–2025) and target livestock commodity type (broiler chicken).

Data Collection Method

Research data were obtained using a digital secondary literature search method. Article searches were performed using the keywords saponin, polyphenol, coccidiosis, *Eimeria*, and broiler chickens. The retrieved articles were subsequently screened in a stepwise manner by assessing title relevance, abstract suitability, and full-text review in accordance with the predetermined inclusion and exclusion criteria.

Data Analysis

Data synthesis and tabulation were performed through critical categorization. Articles meeting the established criteria were further analyzed by grouping them according to the type of active compound, evaluating the compound's metabolic effectiveness within the gastrointestinal tract, and comparing it with conventional anticoccidial agents. As this study constitutes a narrative-analytical literature review, the findings are presented in a descriptive-qualitative manner to

draw conclusions regarding the synergistic potential of both compounds; accordingly, no numerical statistical tests were performed.

RESULTS AND DISCUSSION

Eimeria infection in poultry causes serious damage to the intestinal mucosa due to the invasion and replication of parasites in enterocytes, which triggers inflammation, oxidative stress, and impaired nutrient absorption. These conditions reduce growth performance and feed efficiency, necessitating the development of effective non-antibiotic mitigation strategies (El-Shall *et al.*, 2021). Bioactive compounds from plants, such as saponins and polyphenols, have been widely reported to possess anticoccidial activity through mechanisms that act directly on the parasite or indirectly by enhancing the host's physiological resistance (Benarbia *et al.*, 2022).

The Mechanism of Saponins as Herbal Anticoccidials

Saponins are amphipathic glycosides that are structurally divided into two main types based on their aglycone components (sapogenins): steroidal and triterpenoid saponins. Steroidal saponins have a structural core consisting of a cyclopentanoperhydrophenanthrene (C27) ring that is highly lipophilic, whereas triterpenoid saponins have a C30 pentacyclic carbon core (Timilsena *et al.*, 2023). As herbal anticoccidial agents, plant extracts rich in steroidal saponins (such as *Yucca schidigera*) and triterpenoid saponins (such as *Quillaja saponaria*) act synergistically to specifically target the cell wall of the parasite. The hydrophobic aglycone moiety inserts into the lipid bilayer and strongly binds to cholesterol in the cell membrane of the protozoan *Eimeria* (Cheeke *et al.*, 2000; Felici *et al.*, 2020). This amphipathic interaction forms a sterol-saponin complex that disrupts lipid phase stability, triggering mechanical deformation, pore formation, and leakage of intracellular material, ultimately leading to the lysis of the sporozoite and merozoite stages of the parasite (Clemons *et al.*, 2024; Jiang *et al.*, 2025).

The mechanism of action of these two types of saponins is based on their amphipathic nature; the lipophilic aglycone group binds strongly to cholesterol in the cell membranes of *Eimeria* parasites, whereas its hydrophilic carbohydrate chain (consisting of two or more sugar molecules) remains in the aqueous phase. This interaction forms a sterol-saponin complex that disrupts the membrane potential, increases permeability, causes leakage of vital cellular components, and triggers lysis at various stages of the *Eimeria* life cycle, particularly in the sporozoite and merozoite phases (Hoste *et al.*, 2006; Felici *et al.*, 2020).

The Effects of Membrane Disruption and the Immunomodulatory Effects of Saponins

The destructive interaction between the aglycone groups of saponins and sterols in the parasite cell membrane not only causes direct mechanical damage but also initiates a host immune response. The lysis of *Eimeria* sporozoites and merozoites due to membrane disruption triggers the release of parasite antigens that are more easily recognized by the immune system. In addition to their direct antiparasitic effects, saponins act as effective natural immunomodulators. Saponins enhance the efficiency of antigen presentation by antigen-presenting cells (APCs) and stimulate the production of protective cytokines in the host. This stimulation strengthens the host's cellular immune response against *Eimeria* infection, which in turn significantly reduces the number of oocysts excreted in feces (oocysts per gram [OPG]) and maintains the integrity of the intestinal mucosa (Bafundo *et al.*, 2020; Felici *et al.*, 2020).

Improvement in Intestinal Morphology and Dosage Limits for Saponin Use

Immunological protection and reduction in parasite pressure within the digestive tract directly contribute to the improvement of the anatomical structure of the intestines in infected chickens. This restoration of intestinal mucosal integrity is histologically characterized by an increase in villus height and villus-to-Lieberkuhn crypt ratio, indicating a return to optimal nutrient

absorption capacity (Benarbia *et al.*, 2022). Nevertheless, the effectiveness and safety of saponin use depend heavily on the plant source, specific chemical structure (steroidal vs. triterpenoid), and accuracy of the administered dose. The surfactant or natural detergent properties of saponins require special attention; if administered in excessive doses, their membrane-lysing properties are no longer selective toward parasites but can damage the membranes of the host enterocytes and trigger digestive dysfunction (El-Shall *et al.*, 2021).

Characteristics of the Two Main Commercial Sources: *Yucca schidigera* and *Quillaja saponaria*

To avoid toxic effects and achieve optimal anticoccidial efficacy, the livestock industry uses standardized natural commercial sources. The two main commercial sources of saponins are desert plants: *Yucca schidigera*, native to Mexico, and *Quillaja saponaria*, native to Chile. *Yucca schidigera* is rich in steroidal saponins, whereas *Quillaja saponaria* is rich in triterpenoid saponins. Both plants contain a lipophilic core bound to one or more water-soluble carbohydrate side chains. This dual amphipathic characteristic produces stable natural surfactant (detergent) activity, enabling them to emulsify fats while simultaneously disrupting the cell wall structure of coccidia without irritating the intestinal mucosa when applied at an appropriate concentration (Cheeke, 2000).

The Impact of Saponins on Broiler Performance and Synergistic Effects

The practical application of *Yucca schidigera* and *Quillaja saponaria* extracts in commercial feed has been shown to have a significant impact on the commercial performance of *Eimeria*-infected broiler chickens. Supplementation with this saponin blend has been shown to increase body weight, improve feed efficiency (feed conversion ratio/FCR), suppress the expression of inflammatory cytokines, and improve intestinal permeability during coccidiosis (Clemons *et al.*, 2024; Kozłowski *et al.*, 2022). Comparative studies have shown that saponin-based products (such as Norponin XO2®, which combines *Yucca* and *Trigonella*) demonstrate efficacy comparable to synthetic ionophore anticoccidials, such as monensin. The use of this herbal combination significantly reduced intestinal lesion scores and fully restored broiler growth performance, making it a potential alternative for green livestock production to replace chemical coccidiostats (Benarbia *et al.*, 2022).

The Mechanism of Polyphenols as Herbal Anticoagulants

For a long time, the plant kingdom has provided valuable bioactive compounds used globally to treat various diseases; approximately 11% of the world's essential medicines are derived exclusively from plants. The identification and analysis of these herbal compounds play a crucial role in the discovery of new pharmaceutical resources, as natural preparations have been shown to exhibit anti-inflammatory, antioxidant, and antiparasitic properties through various multitarget mechanisms that are relatively safer and have fewer side effects than synthetic compounds (Davidova *et al.*, 2024).

Among these secondary metabolites, polyphenols stand out as compounds that exhibit strong antimicrobial and antiparasitic activities, even at low concentrations (Górniak *et al.*, 2019; Remmal *et al.*, 2021). Biosynthetically, polyphenols are synthesized from two major aromatic amino acids, tyrosine and phenylalanine, and account for approximately 10% of the total plant secondary metabolite fraction, which protects plants from bacterial, viral, and fungal infections, as well as herbivory (Crozier *et al.*, 2006; Othman *et al.*, 2019).

Structurally, polyphenols are polyaromatic compounds derived from phenol that consist of aromatic rings and multiple hydroxyl groups. Based on the number of phenolic rings and their functional groups, these compounds are classified into five main groups: phenolic acids (such

as gallic acid and caffeic acid), flavonoids (such as catechins, quercetin, and epigallocatechin gallate/EGCG), which is the most abundant group, lignans, stilbenes (such as resveratrol), and tannins, including both condensed and hydrolyzable types (Panche *et al.*, 2016; Yadav *et al.*, 2020).

Direct Antiparasitic Mechanism of Action Against *Eimeria* spp.

As herbal anticoccidial agents against *Eimeria* spp., these polyphenolic compounds often utilize the protection of a hydrophobic carrier matrix, such as vegetable oil or lipid encapsulation, to prolong their retention time and ensure the gradual release of active ingredients along the avian gastrointestinal tract (Tugnoli *et al.*, 2020). This hydrophobic matrix-based delivery system significantly enhances the efficiency of parasite inhibition in the cecum and small intestine and restores growth performance during coccidiosis challenges (Hafeez *et al.*, 2020). The primary mechanism of action of polyphenols is their ability to bind to cellular proteins and disrupt the structural integrity of the parasite membrane. Flavonoids and tannin groups exhibit a high affinity for phospholipids and transmembrane proteins, triggering mechanical disruption and direct lysis of the sporozoite cell wall, the primary infective and pathogenic stage of *Eimeria* (El-Shall *et al.*, 2022; Remmal *et al.*, 2021). In addition, certain polyphenols, particularly tannins, can specifically interact with parasite surface proteins and proteolytic enzymes that are crucial for cellular invasion, thereby significantly reducing the infectivity of *Eimeria* in the intestine (Choi *et al.*, 2022). In addition to external structural damage, polyphenols induce intracellular oxidative stress in protozoa by triggering the accumulation of reactive oxygen species (ROS) and disrupting the mitochondrial respiratory chain of parasites (Cedric *et al.*, 2022). This intracellular cytotoxic activity is associated with the ability of polyphenols to penetrate the oocyst wall, effectively inhibiting sporulation and oocyst maturation within the intestinal lumen (Felici *et al.*, 2021).

Mitigation of Oxidative Stress and Protective Effects on the Host's Intestinal Mucosa

In addition to directly killing parasites (coccidiostatic effect), the penetration of polyphenols into intestinal tissue provides essential secondary protection for the host through potent antioxidant and anti-inflammatory activities (Abdel-Moneim *et al.*, 2020). Massive *Eimeria* infection is known to increase ROS production in intestinal tissue, triggering lipid peroxidation and DNA damage in host cells. Under these conditions, polyphenols act as antioxidant scavengers by donating electrons to neutralize excess ROS while simultaneously downregulating the expression of pro-oxidative enzymes, such as inducible nitric oxide synthase (iNOS) and cyclooxygenase-2 (COX-2) (Abdel-Moneim *et al.*, 2020).

At the cellular and molecular levels, exposure to polyphenols has been shown to attenuate pro-inflammatory cytokine storms (Saeed *et al.*, 2024; El-Shall *et al.*, 2022). Polyphenols inhibit the activation of nuclear factor-kappa B (NF- κ B) transcription factor pathway, thereby suppressing the secretion of systemic pro-inflammatory cytokines, such as IL-1 β , TNF- α , and IL-6, to reduce excessive inflammation in the intestinal mucosa (Saeed *et al.*, 2024).

This anti-inflammatory effect works synergistically with the stimulation of the local mucosal immune system, in which polyphenols enhance goblet cell proliferation and stimulate the secretion of intestinal secretory immunoglobulin A (sIgA) (El-Shall *et al.*, 2022). The combination of reduced parasite populations, free radical neutralization, and inflammation suppression positively impacted the dramatic recovery of intestinal histomorphology. This was clearly demonstrated by the significant recovery of intestinal villi, reduction in crypt depth, and increase in the villi-to-crypt ratio, which are key indicators of restored nutrient absorption capacity and growth performance in broiler chickens (El-Shall *et al.*, 2022).

Synergy Between Saponins and Polyphenols

The synergy between saponins and polyphenols results in significantly higher efficacy, as both compounds act through complementary multitarget mechanisms. From a feed biophysical perspective, the amphiphilic surfactant properties of saponins act as natural emulsifiers that enhance the solubility and bioavailability of hydrophobic polyphenol molecules in intestinal digesta, thereby optimizing their absorption by the host (Kregiel *et al.*, 2021).

The efficacy of this combination stems from the complementary characteristics of each compound, as shown in Table 1. Saponins (such as those from the natural sources *Yucca schidigera* and *Quillaja saponaria*) initiate protection through direct interaction with sterols in the parasite membrane, leading to disruption of the cell membrane, lysis of sporozoites and merozoites, and reduced enterocyte invasion. When interacting with parasites, saponins reduce sporozoite viability and invasion by binding to cholesterol and forming pores in the *Eimeria* cell membrane, facilitating the penetration of polyphenol molecules into the parasite's cytoplasm (Felici *et al.*, 2021; Jiang *et al.*, 2025). Inside the cell, polyphenols lyse transmembrane proteins, disrupt the mitochondrial respiratory chain, and neutralize free radicals to mitigate tissue damage and restore mucosal oxidative homeostasis (Cedric *et al.*, 2022; El-Shall *et al.*, 2022).

The action of these polyphenols is strongly supported by their role as electron donors in neutralizing free radicals (reactive oxygen species/ROS) to reduce oxidative stress, which promotes parasite growth (Abdel-Moneim *et al.*, 2020). Various classes of polyphenols act via different molecular pathways. Flavonoids and phenolic acids inhibit lipid peroxidation, thereby improving mucosal health and nutrient absorption, whereas specific polyphenol subclasses (such as quercetin and catechins) inhibit the NF- κ B pathway and the production of systemic pro-inflammatory cytokines to suppress proliferation and inflammation caused by *Eimeria* (Saeed *et al.*, 2023). In contrast, polyphenols, such as tannins, bind to the surface proteins and proteolytic enzymes of the parasite to halt coccidian invasion and replication (Choi *et al.*, 2022).

Simultaneously, this defense is reinforced by saponins, which regulate the gut microbiota and intestinal mucosa to indirectly suppress *Eimeria* colonization, while also triggering local immunomodulation through enhanced antigen presentation and a Th1 immune response. This combined effect not only massively suppresses oocyst populations and excretion but also improves the host's physiological performance by stimulating the local mucosal immune system (sIgA), goblet cell proliferation, and complete restoration of the intestinal villi architecture (El-Shall *et al.*, 2022).

Based on the comparative data in Table 1, the administration of saponin or polyphenol alone had partial effects, such as a reduction in oocyst shedding, an increase in villus height, a reduction in intestinal lesion scores, an increase in mucosal immunity, an improvement in immune status, a reduction in IL-1 β and TNF- α levels, and an improvement in the feed conversion ratio (FCR). However, when the saponin + polyphenol combination was administered, a synergistic coccidiostatic and immunoprotective effect was observed, as evidenced by a significant reduction in the *Eimeria* population and complete disruption of the parasite life cycle.

This pronounced synergy results in significantly better growth performance and intestinal morphology compared to the efficacy observed when the compounds are administered individually. Thus, the combination of saponins and polyphenols holds great potential as an environmentally friendly and sustainable antiparasitic phytopharmaceutical agent for poultry coccidiosis control.

CONCLUSION

Saponins and polyphenols play complementary roles in mitigating *Eimeria* infections in poultry through distinct, yet mutually supportive, biochemical mechanisms. Saponins directly damage the parasite cell membrane through interactions with sterols, accompanied by immunomodulatory effects that enhance the host defense response. Conversely, polyphenols act as potent antioxidants and anti-inflammatory agents that suppress oxidative stress and repair the integrity of the intestinal mucosa damaged by infections. The combination of these two compounds can disrupt the *Eimeria* life cycle, reduce oocyst shedding, and improve the physiological performance of chickens by enhancing their immunity and restoring microbiota balance. Thus, the use of saponins and polyphenols as antiparasitic phytopharmaceuticals offers an effective, sustainable, and potentially viable natural alternative to synthetic anticoccidial drugs in modern poultry production.

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Table

Table 1. Mechanisms of Action of Saponins and Polyphenols in Mitigating *Eimeria* Infection and Their Physiological Effects on the Host (Poultry)

Compound / Main Source	Primary Target or Mechanism	Effect on the Parasite (<i>Eimeria</i>)	Physiological Effect on the Host (Chicken)	References
Saponins (e.g., <i>Yucca schidigera</i> , <i>Quillaja saponaria</i>)	Interaction with parasite membrane sterols → disruption of the cell membrane	Lysis of sporozoites and merozoites; reduced invasion of enterocytes	Reduced oocyst shedding; improved intestinal morphology (↑ villus height, ↓ lesion score)	Felici <i>et al.</i> (2020); Benarbia <i>et al.</i> (2022)
Saponins	Immunomodulation through enhanced antigen presentation and Th1 response	Increased elimination of intracellular parasites	Enhanced mucosal immunity and feed efficiency	Bafundo <i>et al.</i> (2020); El-Shall <i>et al.</i> (2021); Benarbia <i>et al.</i> (2022)
Saponins	Regulation of gut microbiota and intestinal mucosa	Indirect suppression of <i>Eimeria</i> colonization	Strengthened barrier integrity and microbiota balance	Benarbia <i>et al.</i> (2022)
Polyphenols (Flavonoids, Phenolic Acids)	Antioxidant activity – electron donation for ROS neutralization	Reduced oxidative stress that supports parasite development	Decreased lipid peroxidation, improved mucosal health, and enhanced nutrient absorption	Abdel-Moneim <i>et al.</i> (2020)
Polyphenols (e.g., quercetin, catechin)	Inhibition of the NF-κB pathway and pro-inflammatory cytokine production	Suppressed proliferation and inflammation induced by <i>Eimeria</i> infection	Reduced IL-1β and TNF-α levels; improved intestinal immune status	Saeed <i>et al.</i> (2023)
Tannins (a Polyphenol Class)	Binding to parasite surface proteins and proteolytic enzymes	Inhibition of parasite invasion and replication	Reduced oocyst shedding and improved feed conversion ratio (FCR)	Choi <i>et al.</i> (2022)
Combination of Saponins + Polyphenols	Saponins: direct antiparasitic activity; Polyphenols: antioxidant and immunoprotective effects	Significant reduction in <i>Eimeria</i> populations and disruption of the parasite life cycle	Synergistic effects: improved growth performance and intestinal morphology compared with individual supplementation	El-Shall <i>et al.</i> (2021); Benarbia <i>et al.</i> (2022)