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REVIEW ARTICLE

Advances in Botanical Compounds as Immunomodulatory Alternatives for Coccidiosis Control in Poultry: Progress and Perspectives

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A B S T R A C T

Coccidiosis is a highly pathogenic disease of poultry birds with a very high mortality rate. Poultry sector contributes a significant share of the total GDP of agricultural countries. The annual chicken meat and eggs productions have been estimated at 90 million tons and 1.1 trillion tons respectively. Coccidiosis has a significant financial effect, which is estimated to range between 2.4 to 3 billion USD per year globally. The overall prevalence of avian coccidiosis in house-reared chicks is 80% in Saudi Arabia. Avian coccidiosis poses a significant threat to this huge economic industry, with multiple etiological agents, including *E. maxima, E. acervulina, E. praecox, E. mitis, E. necatrix, E. tenella,* and *E. brunetti.* Vaccines and anticoccidial drugs are in routine use to prevent and control coccidiosis, but their efficacy is reducing because of the regular use. However, *Eimeria* protozoan has developed resistance to existing anticoccidial drugs. There is a dire need for the development of new drugs to overcome this issue. Botanical compounds have been proposed to have significant potent activity against *Eimeria* parasite. The major identified classes of the botanical compounds used against avian coccidiosis are polyphenols, flavonoids, and saponins. This review represents the mechanisms of major botanical compounds and their progress.

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INTRODUCTION

Avian coccidiosis is known as the most economically significant protozoan disease that impacts the poultry production industry worldwide (Mesa-Pineda *et al.*, 2021). Poultry sector has significant importance in the economy of the world as it contributes to the total economy and agriculture industry of any country (Erdaw and Beyene, 2022). The demand of poultry products has remarkably grown among consumers during the last 2 decades, particularly broiler meat and eggs because they are cheap sources of animal protein (Kleyn and Ciacciariello, 2021). The annual chicken meat and eggs productions have been estimated at 90 million tons and 1.1 trillion tons respectively (de Mesquita Souza Saraiva *et al.*, 2022). Coccidiosis has a significant financial effect, which is approximately £10.4 billion at 2016 prices per year globally (Blake *et al.*, 2020). The overall prevalence of avian coccidiosis in house-reared chicks is 80% in Saudi Arabia causing severe economic losses (Qaid *et al.*, 2021). Coccidiosis has substantial attention from farmers and scientists because of its presence regardless of the strict biosecurity measures (Senanayake *et al.*, 2025). Avian coccidiosis has reported to affect the health of both broiler and layer birds and caused a significant decline in the production and quality of meat and eggs (Wickramasuriya *et al.*, 2023). Multiple species of *Eimeria* are the etiological agents of avian coccidiosis, including *E. maxima, E. acervulina, E. praecox, E. mitis, E. necatrix, E. tenella,* and *E. brunetti* (Badri *et al.*, 2024). These different species of *Eimeria* are responsible for causing infection at different sites of the intestine of poultry birds (Mares *et al.*, 2023). *Eimeria* is an apicomplexan protozoan which is highly prevalent and lethal parasite all over the world because of its acute nature of infection and direct life cycle (Aljohani, 2024). Multiple species of *Eimeria* are highly site specific and host-specific, and they do not involve any kind of carrier or vector for their life cycle (Cervero-Aragó *et al.*, 2021). To prevent coccidiosis, there is a need to understand the life cycle and site-specific pathogenesis of *Eimeria* species. The biphasic life cycle of *Eimeria* consists of both reproductive and non-reproductive replication methods

(Bourgoin *et al.*, 2021). The life cycle of *Eimeria* comprises two phases: the exogenous phase, characterized by the secretion of oocysts in the environment, and the endogenous phase, marked by the development of the parasite within the intestine of the host

(Zhao *et al.*, 2024). The endogenous phase of the life cycle is characterized by two forms of reproduction: asexual reproduction, also known as schizogony, and sexual reproduction, which encompasses the differentiation and fertilization of gametes (Zeeshan *et al.*, 2021). The common infectious route of *Eimeria* is fecal-oral route (Choi *et al.*, 2021). However, discussing detailed life cycle of *Eimeria* is beyond the scope of this review. Multiple anticoccidial drugs, including coccidiostat and Coccidioides are in routine use to control coccidiosis (Murshed *et al.*, 2023b). Coccidiostat drugs arrest the cellular reproduction of *Eimeria* while Coccidioides cause cellular destruction by multiple mechanisms (Gao *et al.*, 2024). These anticoccidial drugs had very effective control, but their routine uses results in the development of antimicrobial resistance (Odden *et al.*, 2017).

Antimicrobial resistance is a major health treat for animals and humans as well because of the over- and misuse of different antimicrobial drugs (Hayajneh *et al.*, 2024). *Eimeria* species are reported to develop resistance against various antimicrobial drugs (Abbas *et al.*, 2008). The resistance against antimicrobial drugs is developed through different mechanisms (Abdallah *et al.*, 2023). Vaccines have remained a potential tool for the control and prevention of avian coccidiosis, but there are multiple reports that show the reduced efficacy and resistance against existing vaccines (Zaheer *et al.*, 2022). Scientists have focused on the development of new drugs to control highly pathogenic avian coccidiosis (Gao *et al.*, 2024). The necessity to develop new pharmaceutical products is essential in order to prevent substantial economic loss (Mavrouli *et al.*, 2023). However, the formation of new effective drugs or vaccines needs alternative strategies and effective bioactive compounds (Bouazzaoui *et al.*, 2021). The alternative compounds include peptides, immunogens, probiotics, prebiotics, botanical compounds, vitamins, and many more (Helmy *et al.*, 2023). In the field of pharmacological research, botanical compounds have emerged as a significant category of alternative substances, due to their utilization of diverse bioactive compounds derived from plants in the development of novel pharmaceutical products (Najmi *et al.*, 2022; Hegazy *et al.*, 2023; Tahir *et al.*, 2023; Hailat *et al.*, 2024). Botanical compounds have different therapeutic and medicinal properties, including antioxidants, anti-cancer, anti-inflammatory, antiseptic, cardioprotective, immune boosters, antimicrobials, and various other health properties (Kalu *et al.*, 2024; Saeed *et al.*, 2024). These properties make them perfect candidates for the formulation of new anticoccidial drugs (Ali *et al.*, 2024). However, there are multiple studies that reported the potent results of synergistic effects of botanical compounds and nanoparticles (Essawy *et al.*, 2021; Vaou *et al.*, 2022; Boța *et al.*, 2024). Botanical compounds have proven effective in controlling multiple parasitic, bacterial, fungal, and viral diseases (Deresa and Diriba, 2023). The study on specific bioactive compounds has proven very successful for the treatment of various diseases, including coccidiosis (Biagini *et al.*, 2022; Jamil *et al.*, 2022; Sweidan *et al.*, 2025).

To formulate new chemical drugs for coccidiosis in poultry birds, we require a complete understanding of pathogenesis of *Eimeria* species and the mechanisms of botanical compounds. In this review, we briefly discussed the progress of different botanical compounds against avian coccidiosis and their mechanisms.

Pathogenesis: Coccidiosis in chickens is a parasitic intestinal disease that is caused by intestinal protozoa of *Eimeria* genus (Madlala *et al.*, 2021). The process of infection starts when birds consume sporulated oocysts in litter, feed, water or soil that sporulate when exposed to warm, moist and oxygen-rich conditions, turning them to become infectious (Miska *et al.*, 2024). Oocysts enter the small intestine, whereby the excystation process is initiated by mechanical grinding, digestive enzymes, bile salts and carbon dioxide (López-Osorio *et al.*, 2020). This distributes sporocysts and subsequently sporozoites, which enter the intestinal epithelial cells, by host recognition mechanisms that relate specifically to the parasite and host (Burrell *et al.*, 2020). Sporozoites, after entering the cells, develop into trophozoites and begin asexual reproduction (schizogony), forming merozoites that leave the host cells, causing serious epithelial tissue damage and inflammation (Rivera-Fernández *et al.*, 2022). Merozoites may then infect additional epithelial cells, which increases the damage (Wang *et al.*, 2021). Following two or three cycles, the parasites develop into the sexual stage (Gametogony) producing microgametocytes and macro-gametocytes, which conjoin to produce zygotes that are produced into unpopulated oocysts (Zhu *et al.*, 2025). These oocysts are passed out with the faeces and sporulate under favorable environmental conditions, resulting in infection of other hosts (Zhao *et al.*, 2024). They endanger pathological harm caused by mechanical destruction of epithelial cells, inflammatory reaction, mucosal hemorrhage, but the lesions differ according to their species (Mesa-Pineda *et al.*, 2021). This cellular destruction results in villous atrophy, crypt hyperplasia, malabsorption, impaired weight gain, diarrhea (often bloody), dehydration, and, in severe cases, mortality (Almahallawi, 2025). The host immune response is both innate and adaptive (mainly cellular) which restricts replication of the parasite but is species specific (Humayun *et al.*, 2022). The prevalent complications include secondary bacterial infections that may lead to necrotic enteritis and more loss of products of live implementation because of *Clostridium perfringens* (Mathis *et al.*, 2024). The cycle of ingestion, intestinal invasion, replication of the parasites, destruction of the epithelial lining, resulting inflammation, and environmental contamination characterizes the pathogenesis of the disease (Madlala *et al.*, 2021). This can cause serious penalties on human health and well-being as well as the economy of poultry production (Wickramasuriya *et al.*, 2022).

Limitations of conventional approaches: The traditional approaches that are used in controlling coccidiosis among the chicken are anticoccidial drugs, live vaccines and live-attenuated vaccines (Adjei-Mensah and Atuahene, 2023). The methods possess several disadvantages, including extensive and repeated administration of anticoccidial drugs (Saeed and Alkheraije, 2023). The anticoccidial drugs include ionophores and synthetic chemicals, has resulted in resistant *Eimeria* to drugs (Rogala-Hnatowska *et al.*, 2024). The resistance may decrease the efficacy of such treatments and compel farmers to switch or use combinations of different drugs (Karn *et al.*, 2023). Constant in-feed medication also adds to production costs, and there are doubts about the residue of the drug on poultry products (Das *et al.*, 2024). These residues can also contribute to food safety and consumer confidence, notably in the market where regulations are stringent (Akram *et al.*, 2023). Live vaccines may confer species-specific immunity, although these are costly to manufacture, and have limited cross-immunity between the species of *Eimeria* (Nguyen *et al.*, 2024). In other strains, the vaccine parasites can switch back into virulence or lead to mild disease (Zhao *et al.*, 2024). To be effective, both drugs and vaccines have to be properly administered through good management (Bonanni *et al.*, 2023). Poor biosecurity, ineffective litter management, and environmental conditions that propagate the survival of oocysts cut down their success (Snyder *et al.*, 2021). Because of these issues, integrated control methodologies are increasingly needed (Attree *et al.*, 2021). Multiple botanical compounds have been tested against *Eimeria* and proven effective (Abbas *et al.*, 2023; Băieş *et al.*, 2023; Felici *et al.*, 2023; Geng *et al.*, 2024). Botanical compounds can be perfect candidates to formulate new, more potent chemical drugs because of their diverse medicinal and therapeutic activities (Thomas *et al.*, 2021).

Progress of botanical compounds as alternative control strategies: Botanical compounds have been in use for centuries because of their diverse biological activities (Azizah *et al.*, 2023; Abbas *et al.*, 2025b). Botanical compounds have multiple therapeutic and medicinal activities that make them suitable candidates for the development of drugs to cure multiple diseases and infections (Al-Hoshani *et al.*, 2023; Gul *et al.*, 2024; Iqbal *et al.*, 2024; El-Saadony *et al.*, 2025). Scientists have focused on the identification of specific compounds from different parts of the plants to synthesize new chemical drugs (Pirintsos *et al.*, 2022; Shahzad *et al.*, 2024). Coccidiosis is causing huge economic loss because of the loss in the efficacy of present available drugs and vaccines (Martins *et al.*, 2022). To avoid these losses, new drugs must be formulated. There were multiple research activities and projects performed since last decade to check the efficacy of botanical compounds (Qaid *et al.*, 2021; Coroian *et al.*, 2022). However, there are very few reports of toxic effects of botanical compounds against coccidiosis (Shetshak *et al.*, 2021). The major identified classes of the botanical compounds used against avian coccidiosis are polyphenols, flavonoids, and saponins (Ahmad *et al.*, 2023; Rashid *et al.*, 2024). We briefly discussed the properties and mechanisms of action of these major classes.

Polyphenols: Polyphenols naturally occur botanical compounds that belong to a major class of phenols (Hassan and Mohemmed, 2024). Polyphenols are botanical compounds that contain at least one aromatic ring, which is attached to one or more hydroxyl groups (Saracila *et al.*, 2021). Polyphenols are well known for their diverse biological properties (Manso *et al.*, 2021). These beneficial properties of polyphenols make them suitable candidates to be used for the prevention of avian coccidiosis (El-Ghareeb *et al.*, 2023).

Polyphenols could control poultry coccidiosis by both direct and indirect means (Hascoët *et al.*, 2025). The direct mechanism of polyphenols against poultry coccidiosis involves inhibition of the development of different life stages of *Eimeria* (Song *et al.*, 2023). Polyphenols are involved in the disruption of ion transport channels of potassium (K^+) and sodium (Na^+) ions (Panickar and Anderson, 2011; Miranda *et al.*, 2023). Any disruption in the ion channel causes severe changes in the integrity of the cell, osmolarity, pH, functionality of the cell, and transportation of ions inside the cell (Awad *et al.*, 2017). All these changes results in cellular imbalance, altered membrane permeability and ultimately cell death (Abdel-Gaber *et al.*, 2023). Some compounds of polyphenols cause a disruption in the energy mechanisms of *Eimeria* cell leading to the inhibition of ATP synthesis (Basiouni *et al.*, 2023). Energy imbalance directly leads to the cellular death of *Eimeria* (Galli *et al.*, 2019). However, the indirect mechanisms of polyphenols include improvement in the gut health and immune system of the chicken (Das *et al.*, 2020). The immunomodulatory effects of polyphenols include antioxidant activities, modulation of immune cells, and anti-inflammatory actions (Cuevas *et al.*, 2013). Also, the combined effect of polyphenols with different functional amino acids can improve nutrient digestibility and improvements in the growth performance of the birds infected with *Eimeria* (Galamatis *et al.*, 2025). Considering all the positive health and anticoccidial activities of polyphenols, we suggest that polyphenols can be a good source for the synthesis of new anticoccidial drugs. However, the safety index and toxic effects of polyphenols must be checked through further research.

Flavonoids: Flavonoids are yellow colored naturally occurring botanical compounds present in a large variety of plants (Godlewska *et al.*, 2023). The simplest botanical compounds of flavonoids contain minimum 2 phenyl rings, which are attached with one heterocyclic ring (Zhang *et al.*, 2023). Flavonoids are primarily present in multiple plant species in 2 different forms that are free aglycone and glycosidic-bond form (Tian *et al.*, 2024). However, the most consumable form of flavonoids in diet is glycosidic-bond form (Wang *et al.*, 2023). Multiple botanical compounds of flavonoids are infamous for their diverse mechanisms against different parasitic, bacterial, and other infectious diseases (Kováč *et al.*, 2022). Different mechanisms of flavonoids include anti-inflammatory, anti-cancer, antimicrobial, and anti-oxidative properties (Mucha *et al.*, 2021).

Flavonoids are very important botanical compounds for the control of avian coccidiosis (Tchodo *et al.*, 2024). Flavonoids have the ability to inhibit multiple *Eimeria* species to enter in the host, including *E. maxima* and *E. Necatrix* (Murshed *et al.*, 2023a). Flavonoids block the entry of *Eimeria* species in the intestine of the chicken by disturbing the host-parasite interaction (Kasem *et al.*, 2024). Multiple studies have reported the anti-inflammatory effects of flavonoids against avian coccidiosis (Abdel-Gaber *et al.*, 2023; Aljohani, 2024; Hascoët *et al.*, 2025; Sweidan *et al.*, 2025). Flavonoids stop the inflammation by controlling the interleukins, interferon-gamma, and inflammatory cytokines (Al-Khayri *et al.*, 2022). The anti-inflammatory activity of flavonoids reduces the clinical signs and symptoms of avian coccidiosis (Park *et al.*, 2023). Some botanical compounds of flavonoids can significantly alter the permeability of the cell membrane of *Eimeria* (Fig. 1). Any alteration in the membrane permeability of *Eimeria* results in the removal of important cellular components which ultimately lead to the death of *Eimeria* (Balta *et al.*, 2021). However, some other reports stated the interference of different flavonoids with the energy mechanisms of *Eimeria* (Biallah *et al.*, 2022; Galamatis *et al.*, 2025). Energy mechanisms are very crucial for the survival of *Eimeria,* but flavonoids cause disruption in the synthesis of ATP, leading to cellular death (Bai *et al.*, 2025). Flavonoids can be used to formulate new anticoccidial drugs, but their toxicity and safety index must be evaluated in chickens.

Saponins: Saponins are naturally occurring botanical compounds that are known because of their soapy nature (Mohlakoana and Moteetee, 2021). The simplest botanical compounds of saponins have at least one glycosidic linkage present between a sugar chain (glycone) and a non-sugar, organic molecule (aglycone) (Alsayeqh, 2025a). In the past, saponins were mainly used for the synthesis of soap, steroids, and drug-adjuvants (Rieger, 2020). But in recent few years, scientists have studied the medicinal properties of saponins, and effective results were observed (Sharma *et al.*, 2023). Multiple researchers have conducted research on specific saponin compounds for the control and prevention of avian coccidiosis. Scientists have observed potent results of botanical compounds of saponins against the control of avian coccidiosis (Bafundo *et al.*, 2021).

Botanical compounds of saponins have diverse mechanisms of action against multiple life stages of different *Eimeria* species (Geng *et al.*, 2024). Oxidative damage has been done in the cells and tissues of the birds during coccidiosis, which is also known as oxidative stress (Zhang *et al.*, 2024). Oxidative stress is the result of the imbalance in the reactive oxygen species (ROS) and saponins have the ability of the bird to neutralize them (Basiouni *et al.*, 2023; Ebrahimi *et al.*, 2023). Saponins have significant antioxidant properties that help them to reduce or neutralize the ROS produced through cellular inflammation and processes (Khan *et al.*, 2022). Neutralization of ROS results in the recovery of cells and tissues of the infected bird (Han *et al.*, 2024). Saponins are also reported to alter the membrane permeability of multiple *Eimeria* species (Benarbia *et al.*, 2022). Because of the surfactant properties of saponins, they interact with the cell membrane of *Eimeria* and destabilize it, including merozoites and sporozoites (Alsayeqh, 2025b). The destabilization of the cell membrane of *Eimeria* leads to cellular death and inhibition in the continuation of its life cycle (Britez *et al.*, 2023). Saponins can be used in the formation of new effective anticoccidial drugs. However, further research on the toxicity and safety index of saponins in chickens must be conducted.

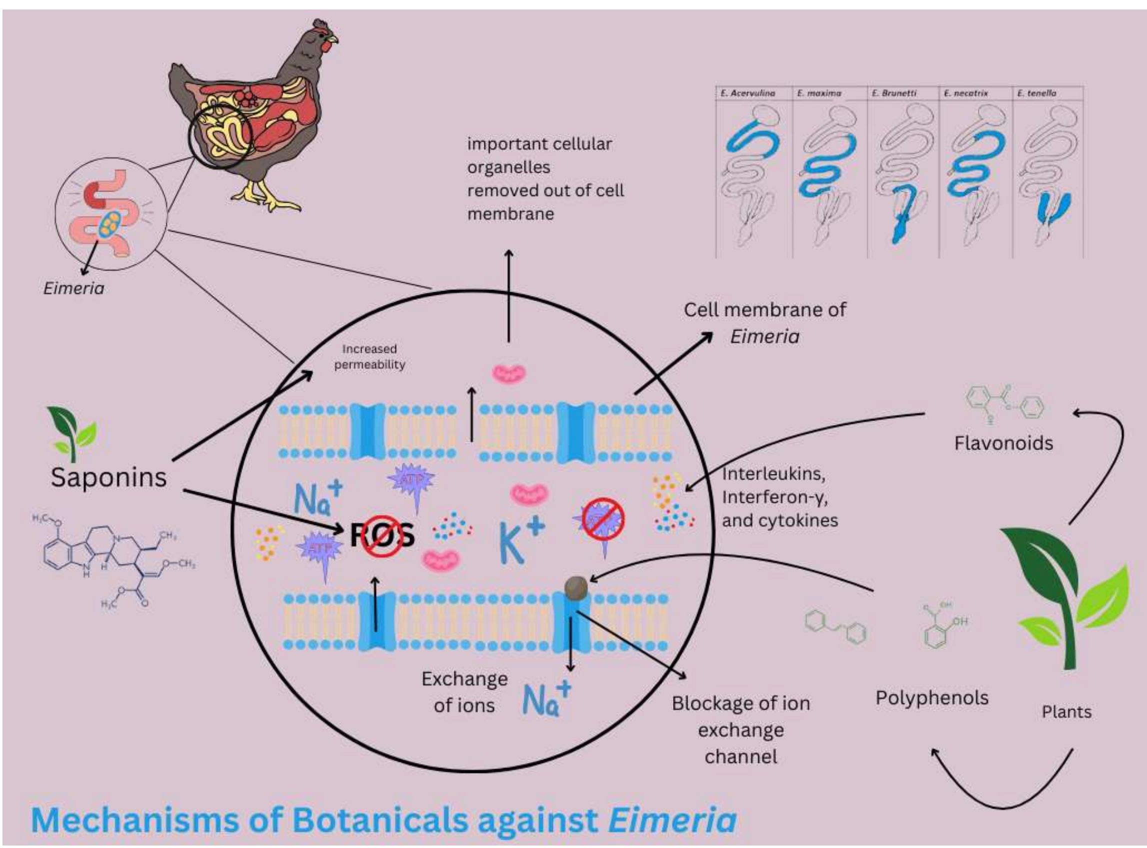

Fig. 1: Mechanism of actions of botanical compounds against *Eimeria*.

Immune-stimulating mechanisms of botanical compounds: The botanical compounds stimulate the poultry immune response to coccidiosis through improvements in gut barrier integrity, enhanced beneficial gut microbiota, generation of immunomodulatory metabolites, and direct anti-antioxidant, anti-inflammatory (Park *et al.*, 2023). There are numerous botanical compounds out of which the most prominent compounds used against coccidiosis include saponins, flavonoids, and polyphenols (Jamil *et al.*, 2022). The plant-based compounds aid the host immune system, promote gut health, and prevent *Eimeria* parasites (Chen *et al.*, 2024). Detailed mechanisms of action of stimulation in immune response of chickens against coccidiosis are as follows:

Gut barrier integrity: *Eimeria* species are responsible for causing coccidiosis in chickens, replicates in the intestinal tract of the birds (Jebessa *et al.*, 2022). *Eimeria* parasites cause severe destruction and inflammation in the intestinal tract of chickens (Xu *et al.*, 2022). The tight junctions present in the intestinal cell layers that work as seal are damaged by the *Eimeria* species resulting in the leaking of harmful material inside the host body (Ali *et al.*, 2025). However, the parasite also causes damage to the structure of intestinal lining that compromises cell integrity, permeability, and gut barrier (Aleman *et al.*, 2023). Botanical compounds play vital role in improving intestinal health and gut barrier integrity. The botanicals significantly reduce intestinal lesions, inflammation, improve the tight junction's integrity, and intestinal morphology (Martins-Gomes *et al.*, 2024). Improvement in intestinal morphology includes the restoration of the normal intestinal cell lining and villi that plays very significant role in the barrier junction and nutrition absorption (Gieryńska *et al.*, 2022).

Beneficial gut microbiota: Lactobacillus and bifidobacterium are well known as beneficial gut microbiota of chicken (Fathima *et al.*, 2022). These bacteria play very important role in improving health of chicken by assisting in the digestion mechanisms, enhancing the immune system, and improving disease resistance against coccidiosis (Wickramasuriya *et al.*, 2022). The key mechanisms of lactobacillus and bifidobacterium include production of antimicrobial agents, empowering the host immune response against *Eimeria*, and promoting the other bacterial that are beneficial for the host immune system (Pewan *et al.*, 2025). Useful microbes contribute to fermentation of dietary fibers and mucus and subsequently produce short-chain fatty acids (SCFAs) (Vinelli *et al.*, 2022). These SCFAs can be used as a source of energy and help keep the gut healthy (Singh and Kim, 2021). However, some beneficial bacteria can enhance nutrient uptake by enhancing the organization of the small intestine, resulting in improved growth and feed conversion (Duarte *et al.*, 2023). Balanced gut microbiota gives the advantage to the beneficial bacteria, which competes with and represses pathogenic microbes, i.e., *Eimeria* (Aldawood *et al.*, 2025).

Antioxidant properties: Coccidiosis causes oxidative stress in the intestine, which may cause injury to the intestinal cells and decrease nutrients (Li *et al.*, 2022). Multiple botanical compounds have been reported to mitigate the oxidative stress caused by *Eimeria* in poultry birds (Ewais *et al.*, 2023). The most prominent botanicals reported to reduce oxidative stress and anticoccidial activities include garlic, aloe vera, and oregano (Hascoët *et al.*, 2025). The botanical compounds aid in preservation of nutrients that are essential for chicken growth making them available for the birds to absorb and utilize (Shehata *et al.*, 2022). However, research is still ongoing in the exact antioxidative mechanisms of various plant-based compounds and essential oils.

Table 1: Progress of botanical compounds.

Sr. no.	Plant used	Family of plant	Bioactive compound	Part of plant used	Investigation medium	Infection type	Infection dose (oocysts)	Toxicity	Results	References
1	*Enteromorpha prolifera*	Ulvales	Polysaccharide	NA	In vivo	Mixed *Eimeria* species	1.5×10^4	NA	More Weiwei gain and reduced intestinal lesions.	(Muluneh *et al.*, 2024)
2	*Piper betle* L.	Piperaceae	Eugenol and naphthalene,	Leaves	In vivo	*E. tenella*	3×10^4	No toxicity was observed	Sporulation-inhibitory and oocysticidal activities were observed.	(Ristanti *et al.*, 2024)
3	*Artemisia annua*, *Quercus infectoria*, and *Allium sativum*	Asteraceae, Fagaceae, and Amaryllidaceae, respectively	Tannins, ajoene, gallic acid, allicin, gallotannins	NA	In vivo	Mixed *Eimeria* species	200,000	NA	Herbal mixture causes reduction in oocysts earlier than untreated groups.	(Ghafouri *et al.*, 2023)
4	*Carica papaya, Combretum micranthum, Sarcocephalus latifolius, Azadirachta indica,*and*Vernonia amygdalina*	Caricaceae, Combretaceae, Rubiaceae, Meliaceae, and Asteraceae, respectively	Phenols and flavonoids	Seeds, leaves, roots, Leaves, and Leaves, respectively	In vitro	Mixed *Eimeria* species	NA	NA	Inhibition of sporulation of *Eimeria* in vitro.	(Tchodo *et al.*, 2024)
5	NA	NA	Silymarin, dihydroartemisinin, quercetin,nerolidol,	Compounds were commercially purchased	In vivo	*E. tenella*	10,000	Dihydroartemisinin and genistein have high FCR and toxicity in	Significant reduction in the cecal lesions was seen.	(Hou *et al.*, 2024)

			resveratrol, genistein, and diclazuril					broiler 6cervul.		
6	*Taraxacum officinale*	Asteraceae	Phenolics and terpenes	NA	In vivo	Mixed *Eimeria* species	NA	No significant negative or toxic effects were observed in this study.	The extract significantly increased the growth performance, improved intestinal lesions, and reduced shedding of oocysts.	(Arczewska-Włosek *et al.*, 2023)
7	*Areca catechu* L.	Arecaceae	Alkaloids, polyphenols, and polysaccharides	Compounds were commercially purchased	In vivo	*E. tenella*	2.5×10^4	NA	Enhanced growth performance, reduced inflammation, 6cervulin bloody diarrhea, and a decline in oocyst count.	(Ma *et al.*, 2025)
8	NA	NA	Myricetin (flavonoid)	NA	In vivo	*E. tenella, E. maxima,* and *E. acervulina*	5.0×10^3, 7.0×10^3, 3.5×10^4, respectively	NA	Improved body weight gain, significant decrease in lipid peroxidation biomarkers, 6cervulin ROS contents, and 6cervulin oocysts count.	(El-Ghareeb *et al.*, 2023)
9	*Aloe Vera*	Asphodelaceae	Acemannan (polysaccharide)	Leaves	In vivo	*E. tenella*	5×10^4	*A. vera* gel had no significant negative effects on the 6cervulin of birds.	The Cominco effects of *A. vera* reduced antimicrobial resistance and improved health parameters with 6cervulin oocyst shedding.	(Hassan *et al.*, 2024)
10	*Glycyrrhiza glabra*	Fabaceae	Terpenoids, flavonoids, saponins, phenols, and tannins	Roots	In vivo	*E. tenella*	5×10^4	NA	Effective results have been seen when the extracted was used in a combination with maduramicin.	(Elbasuni *et al.*, 2024)
11	*Opuntia ficus-indica*	Cactaceae	Phenolics and flavonoids	Flower	In vitro	Mixed *Eimeria* species	24.5×10^5	NA	*Opuntia ficus-indica* extract shows significant anticoccidial activity in vitro.	(Amrane-Abider *et al.*, 2023b)
12	*Spinacia oleracea*	Amaranthaceae	Polyphenols and flavonoids	Whole plant	In vivo & In vitro	*E. tenella*	5×10^4	NA	Spinach inhibits the sporulation of *E. tenella* oocysts, improved growth parameters, and restores the goblet cells.	(Ewais *et al.*, 2023)
13	*Opuntia Ficus-Indica*	Cactaceae	Phenolics	Fruit	In vitro	Mixed *Eimeria* species	24.5×10^5	NA	*Opuntia Ficus-Indica* extract has great antioxidant activities that results in the destruction of *Eimeria* oocysts.	(Amrane-Abider *et al.*, 2023a)
14	*Beta vulgaris*	Amaranthaceae	NA	Roots	In vivo	Mixed *Eimeria* species	50,000	NA	Maximum immunomodulatory response was recorded with *B. vulgaris* at 300 mg/kg of body weight. Improvement in the immune response results in anticoccidial activities.	(Abbas *et al.*, 2025a)
15	*Trachyspermum ammi*	Apiaceae	Essential oil	Essential oil purchased commercially	In vivo	Mixed *Eimeria* species	50000	Improved serum chemistry and no toxic effects were observed during experimentation	Significant improvement in FCR, growth rate, serum and hematological profiles, and reduction in oocysts shedding.	(Fayyaz *et al.*, 2025)
16	*Hibiscus sabdariffa*	Malvaceae	NA	calyx	In vivo	*E. tenella* and *E. necatrix*	3×10^3	NA	The synergistic effect of *H. sabdariffa* with anticoccidial drugs showed potent activity against *Eimeria* oocysts.	(Abdulkareem *et al.*, 2024)

Conclusions: Coccidiosis is a highly pathogenic disease of poultry birds with a very high mortality rate. The poultry sector contributes a significant share of the total GDP of agricultural countries. The annual chicken meat and eggs productions have been estimated at 90 million tons and 1.1 trillion tons respectively. Coccidiosis has a significant financial effect, which is estimated to range between 2.4 to 3 billion USD per year globally. The overall prevalence of avian coccidiosis in house-reared chicks is 80% in Saudi Arabia. Avian coccidiosis poses a significant threat to this huge economic industry, with multiple etiological agents, including *E. maxima, E. acervuline, E. praecox, E. mitis, E. necatrix, E. tenella,* and *E. brunetti.* Vaccines and anticoccidial drugs are in routine use to prevent and control coccidiosis, but their efficacy is reducing because of the regular use. However, *Eimeria* protozoan has developed resistance to existing anticoccidial drugs. There is a dire need for the development of new drugs to overcome this issue. Botanical compounds have been proposed to have significant potent activity against *Eimeria* parasite. The major identified classes of the botanical compounds used against avian coccidiosis are polyphenols, flavonoids, and saponins. The mechanisms of polyphenols, flavonoids, and saponins include changes in the permeability of the cell membrane of *Eimeria*, improvement in gut health, improved immune functions, and reduction in oxidative stress. Biologically active botanical compounds can be used to formulate new potent anticoccidial drugs with reduced issues of antimicrobial resistance. However, further research must be conducted to check the toxicity and safety indices of polyphenols, flavonoids, and saponins.

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REFERENCES

Abbas A, Hussain K, Aleem MT *et al.*, 2025a. Immunomodulatory Potential of Sugar Beet (Beta vulgaris) Against Coccidiosis in Broiler Chickens. Kafkas Universitesi Veteriner Fakultesi Dergisi 31(3).

Abbas RZ, Iqbal Z, Sindhu ZD *et al.*, 2008. Identification of cross-resistance and multiple resistance in Eimeria tenella field isolates to commonly used anticoccidials in Pakistan. Journal of Applied Poultry Research 17(3):361-368.

Abbas RZ, Qureshi MA and Saeed Z, 2025b. Botanical compounds: A promising control strategy against Trypanosoma cruzi. Boletín Latinoamericano y del Caribe de Plantas Medicinales y Aromáticas 24(3):308-327.

Abbas RZ, Saeed Z, Bosco A *et al.*, 2023. Botanical control of coccidiosis in ruminants. Pak Journal of Agricultural Science 60(4)

Abdallah EM, Alhatlani BY, de Paula Menezes R *et al.*, 2023. Back to nature: Medicinal plants as promising sources for antibacterial drugs in the post-antibiotic era. Plants 12(17):3077.

Abdel-Gaber R, Hawsah MA, Al-Otaibi T *et al.*, 2023. Biosynthesized selenium nanoparticles to rescue coccidiosis-mediated oxidative stress, apoptosis and inflammation in the jejunum of mice. Frontiers in Immunolology 14:1139899.

Abdulkareem AM, Awe S, Ajao AT *et al.*, 2024. Assessment of the synergistic effects of Hibiscus sabdariffa calyx extract and anticoccidial drugs against Eimeria infections in broiler chicks. Microbes and Infectious Diseases 10.21608/mid.2024.245491.1644.

Adjei-Mensah B and Atuahene CC, 2023. Avian coccidiosis and anticoccidial potential of garlic (Allium sativum L.) in broiler production: a review. Journal of Applied Poultry Research 32(1):100314.

Ahmad S, Humak F, Ahmad M *et al.*, 2023. Phytochemicals as alternative anthelmintics against poultry parasites: a review. Agrobiolgical Records (12):34-45.

Akram MS, Rani Z, Samad MA *et al.*, 2023. Public health-associated issues becaus e of chemical drug residues in poultry product. Continental Veterinary Journal 3(2):15-23.

Al-Hoshani N, Al Syaad KM, Saeed Z *et al.*, 2023. Anticoccidial Activity of Star Anise (Illicium verum) Essential Oil in Broiler Chicks. Pakistan Veterinary Journal 43(3).

Al-Khayri JM, Sahana GR, Nagella P *et al.*, 2022. Flavonoids as potential anti-inflammatory molecules: A review. Molecules 27(9):2901.

Aldawood N, Melebary SJ, Alghamdi MS *et al.*, 2025. Evaluation of Gum Arabic Extract for Enhancing Growth Performance, Blood Parameters, Oxidative Status, Gut Microbiota, and Organ Histology in Heat-Stressed Rabbits. Kafkas Universitesi Veteriner Fakultesi Dergisi 31(2).

Aleman RS, Moncada M and Aryana KJ, 2023. Leaky gut and the ingredients that help treat it: a review. Molecules 28(2):619.

Ali M, Xu C, Wang M *et al.*, 2025. Gut Barrier Dysfunction and Microbiota Variations in Cryptosporidiosis: A Comprehensive Review. Veterianry Sciences 12(2):85.

Ali S, Yousaf N, Usman M *et al.*, 2024. Volvariella volvacea (paddy straw mushroom): A mushroom with exceptional medicinal and nutritional properties. Heliyon 10(21).

Aljohani ASM, 2024. Phenolics of Botanical Origin for the Control of Coccidiosis in Poultry. Pakistan Veterinary Journal 44(2).

Almahallawi RS, 2025. The Influences of Spirulina platensis as an Eco-friendly Anticoccidial Agent on Growth Performance, Blood Biochemistry, Immune Response, Gut Microbiota in Eimeria Challenged Broiler Chickens. Kafkas Univ Vet Fak Derg 31(4).

Alsayeqh AF, 2025a. Botanicals: A Promising Control Strategy Against Highly Zoonotic Foodborne Trichinosis. Kafkas Universitesi Veteriner Fakultesi Dergisi 31(2).

Alsayeqh AF, 2025b. Saponins and Their Role as Vaccine Adjuvant Against Coccidiosis in Poultry. Kafkas Universitesi Veteriner Fakultesi Dergisi 31(3).

Amrane-Abider M, Imre M, Herman V *et al.*, 2023a. Opuntia Ficus-Indica Peel By-Product as a Natural Antioxidant Food Additive and Natural Anticoccidial Drug. Foods 12(24):4403.

Amrane-Abider M, Imre M, Herman V *et al.*, 2023b. Bioactive compounds and in vitro antioxidant and anticoccidial activities of Opuntia ficus-indica flower extracts. Biomedicines 11(8):2173.

Arczewska-Włosek A, Świątkiewicz S, Tomaszewska E *et al.*, 2023. Effects of anticoccidial vaccination and Taraxacum officinale extract on the growth performance, biochemical parameters, immunity, and intestinal morphology of eimeria-challenged chickens. Life 13(9):1927.

Attree E, Sanchez-Arsuaga G, Jones M *et al.*, 2021. Controlling the causative agents of coccidiosis in domestic chickens; an eye on the past and considerations for the future. CABI Agriculture and Bioscience 2(1):37.

Awad WA, Hess C and Hess M, 2017. Enteric pathogens and their toxin-induced disruption of the intestinal barrier through alteration of tight junctions in chickens. Toxins 9(2):60.

Azizah NS, Irawan B, Kusmoro J *et al.*, 2023. Sweet basil (Ocimum basilicum L.)-A review of its botany, phytochemistry, pharmacological activities, and biotechnological development. Plants 12(24):4148.

Badri M, Olfatifar M, Hayati A *et al.*, 2024. The global prevalence and associated risk factors of Eimeria infection in domestic chickens: A systematic review and meta-analysis. Veterinary Medicine and Science 10(4):e1469.

Bafundo KW, Gomez L, Lumpkins B *et al.*, 2021. Concurrent use of saponins and live coccidiosis vaccines: the influence of a quillaja and yucca combination on anticoccidial effects and performance results of coccidia-vaccinated broilers. Poultry Science 100(3):100905.

Bai R, Wang H, Yang T *et al.*, 2025. Mechanisms of Mitochondria-Mediated Apoptosis During Eimeria tenella Infection. Animals 15(4):577.

Băieş M-H, Györke A, Cotuţiu V-D *et al.*, 2023. The In Vitro Anticoccidial Activity of Some Herbal Extracts against Eimeria spp. Oocysts Isolated from Piglets. Pathogens 12(2):258.

Balta I, Marcu A, Linton M *et al.*, 2021. The in vitro and in vivo anti-virulent effect of organic acid mixtures against Eimeria tenella and Eimeria bovis. Scientific Reports 11(1):16202.

Basiouni S, Tellez-Isaias G, Latorre JD *et al.*, 2023. Anti-inflammatory and antioxidative phytogenic substances against secret killers in poultry: current status and prospects. Veterinary Science 10(1):55.

Benarbia MeA, Gaignon P, Manoli C *et al.*, 2022. Saponin-Rich Plant Premixture supplementation is as efficient as Ionophore Monensin supplementation under experimental Eimeria spp challenge in broiler chicken. Frontiers in Veterinary Science 9:946576.

Biagini L, Galosi L, Roncarati A *et al.*, 2022. The role of nutraceuticals and phytonutrients in chickens' gastrointestinal diseases. Animals 12(7):892.

Biallah MB, Lawal IA, Abdu PA *et al.*, 2022. Phytochemical profile of the methanolic leaf extract of Vernonia amygdalina Del. and in vitro anticoccidial effect of its fractions against Eimeria tenella. International Journal of Innovative Research & Development 11(11):67-72.

Blake DP, Knox J, Dehaeck B *et al.*, 2020. Re-calculating the cost of coccidiosis in chickens. Veterinary Research 51(1):115.

Bonanni P, Steffen R, Schelling J *et al.*, 2023. Vaccine co-administration in adults: an effective way to improve vaccination coverage. Human Vaccines & Immunotherapeutics 19(1):2195786.

Boța M, Vlaia L, Jîjie A-R *et al.*, 2024. Exploring synergistic interactions between natural compounds and conventional chemotherapeutic drugs in preclinical models of lung cancer. Pharmaceuticals 17(5):598.

Bouazzaoui A, Abdellatif AAH, Al-Allaf FA *et al.*, 2021. Strategies for vaccination: conventional vaccine approaches versus new-generation strategies in combination with adjuvants. Pharmaceutics 13(2):140.

Bourgoin G, Portanier E, Poirel M-T *et al.*, 2021. Reproductive females and young mouflon (Ovis gmelini musimon× Ovis sp.) in poor body condition are the main spreaders of gastrointestinal parasites. Parasitology 148(7):809-818.

Britez JD, Rodriguez AE, Di Ciaccio L *et al.*, 2023. What do we know about surface proteins of chicken parasites Eimeria? Life 13(6):1295.

Burrell A, Tomley FM, Vaughan S *et al.*, 2020. Life cycle stages, specific organelles and invasion mechanisms of Eimeria species. Parasitology 147(3):263-278.

Cervero-Aragó S, Desvars-Larrive A, Lindner G *et al.*, 2021. Surface waters and urban brown rats as potential sources of human-infective Cryptosporidium and Giardia in Vienna, Austria. Microorganisms 9(8):1596.

Chen P, Liu K, Yue T *et al.*, 2024. Plants, plant-derived compounds, probiotics, and postbiotics as green agents to fight against poultry coccidiosis: A review. Animal Research and One Health 3:240–260.

Choi J, Ko H, Tompkins YH *et al.*, 2021. Effects of Eimeria tenella infection on key parameters for feed efficiency in broiler chickens. Animals 11(12):3428.

Coroian M, Pop LM, Popa V *et al.*, 2022. Efficacy of Artemisia annua against coccidiosis in broiler chickens: A field trial. Microorganisms 10(11):2277.

Cuevas A, Saavedra N, Salazar LA *et al.*, 2013. Modulation of immune function by polyphenols: possible contribution of epigenetic factors. Nutrients 5(7):2314-2332.

Das Q, Islam MR, Lepp D *et al.*, 2020. Gut microbiota, blood metabolites, and spleen immunity in broiler chickens fed berry pomaces and phenolic-enriched extractives. Frontiers and Veterinary Science 7:150.

Das SC, Tasmin MZ, Afrin A *et al.*, 2024. Challenges in the profitability of small-scale broiler farming by avoiding injudicious use of drugs and additives. Heliyon 10(3)

de Mesquita Souza Saraiva M, Lim K, do Monte DFM *et al.*, 2022. Antimicrobial resistance in the globalized food chain: A One Health perspective applied to the poultry industry. Brazilian Journal of Microbiology 53(1):465-486.

Deresa EM and Diriba TF, 2023. Phytochemicals as alternative fungicides for controlling plant diseases: A comprehensive review of their efficacy, commercial representatives, advantages, challenges for adoption, and possible solutions. Heliyon 9(3)

Duarte ME, Garavito-Duarte Y and Kim SW, 2023. Impacts of F18+ Escherichia coli on intestinal health of nursery pigs and dietary interventions. Animals 13(17):2791.

Ebrahimi R, Ebrahimi M and Shakeri M, 2023. Mitigating the adverse effects of lead and cadmium heavy metals-induced oxidative stress by phytogenic compounds in poultry. Poultry 2(2):235-251.

El-Ghareeb WR, Kishawy ATY, Anter RGA *et al.*, 2023. Novel antioxidant insights of myricetin on the performance of broiler chickens and alleviating experimental infection with Eimeria spp.: crosstalk between oxidative stress and inflammation. Antioxidants 12(5):1026.

El-Saadony MT, Saad AM, Mohammed DM *et al.*, 2025. Medicinal plants: bioactive compounds, biological activities, combating multidrug-resistant microorganisms, and human health benefits-a comprehensive review. Frontiers in Immunolology 16:1491777.

Elbasuni SS, Taie HAA, Gawad SMA *et al.*, 2024. Efficacy of dietary supplements of Glycyrrhiza glabra (Licorice) and maduramicin alone or in combination with Eimeria tenella infected chicks: A clinical study and molecular docking. Open Veterinary Journal 14(1):225.

Erdaw MM and Beyene WT, 2022. Trends, prospects and the socio-economic contribution of poultry production in sub-Saharan Africa: a review. World's Poultry Science Journal 78(3):835-852.

Essawy E, Abdelfattah MS, El-Matbouli M *et al.*, 2021. Synergistic effect of biosynthesized silver nanoparticles and natural phenolic compounds against drug-resistant fish pathogens and their cytotoxicity: an in vitro study. Marine Drugs 19(1):22.

Ewais O, Abdel-Tawab H, El-Fayoumi H *et al.*, 2023. Administration of Ethanolic Extract of Spinacia oleracea Rich in Omega-3 improves oxidative stress and goblet cells in broiler chickens infected with Eimeria tenella. Molecules 28(18):6621.

Fathima S, Shanmugasundaram R, Adams D *et al.*, 2022. Gastrointestinal microbiota and their manipulation for improved growth and performance in chickens. Foods 11(10):1401.

Fayyaz MR, Hussain K, Abbas A *et al.*, 2025. Anticoccidial Effects of Trachyspermum ammi Essential Oil Against Caecal Coccidiosis in Broiler Chickens. Kafkas Universitesi Veteriner Fakultesi Dergisi 31(4): 451.

Felici M, Tugnoli B, Ghiselli F *et al.*, 2023. Investigating the effects of essential oils and pure botanical compounds against Eimeria tenella in vitro. Poultry Science 102(10):102898.

Galamatis D, Panitsidis I, Mantzios T *et al.*, 2025. Assessment of a Natural Phytobiotic Mixture as Feed Additive for Broiler Chicken: Studies on Animal Performance, Gut Health, and Antioxidant Status After Experimental Infection with Eimeria spp. Poultry 4(1):4.

Galli GM, Baldissera MD, Griss LG *et al.*, 2019. Intestinal injury caused by Eimeria spp. impairs the phosphotransfer network and gain weight in experimentally infected chicken chicks. Parasitology Research 118(5):1573-1579.

Gao Y, Sun P, Hu D *et al.*, 2024. Advancements in understanding chicken coccidiosis: from Eimeria biology to innovative control strategies. One Health Advances 2(1):6.

Geng T, Ruan X, Xie Y *et al.*, 2024. Anticoccidial activity of a botanical natural product based on eucalyptus, apigenin and eugenol against Eimeria tenella in broiler chickens. Parasites & Vectors 17(1):327.

Ghafouri SA, Ghaniei A, Sadr S *et al.*, 2023. Anticoccidial effects of tannin-based herbal formulation (Artemisia annua, Quercus infectoria, and Allium sativum) against coccidiosis in broilers. Journal of Parasitic Diseases 47(4):820-828.

Gieryńska M, Szulc-Dąbrowska L, Struzik J *et al.*, 2022. Integrity of the intestinal barrier: the involvement of epithelial cells and microbiota—a mutual relationship. Animals 12(2):145.

Godlewska K, Pacyga P, Najda A *et al.*, 2023. Investigation of chemical constituents and antioxidant activity of biologically active plant-derived natural products. Molecules 28(14):5572.

Gul ST, Raza R, Hannan A *et al.*, 2024. Potential of a medicinal plant Urtica dioica (Stinging nettle) as a feed additive for animals and birds: A review. Agrobiological Records 17: 110-118.

Hailat AM, Abdelqader AM and Gharaibeh MH, 2024. Efficacy of Phyto-Genic Products to Control Field Coccidiosis in Broiler Chickens. International Journal of Veterianry Science 13(3):266-272.

Han X, Huang Y and Hao J, 2024. Avian coronavirus infectious bronchitis virus activates mitochondria-mediated apoptosis pathway and affects viral replication by inducing reactive oxygen species production in chicken HD11 cells. Biology 13(7):491.

Hascoët A-S, Torres-Celpa P, Riquelme-Neira R *et al.*, 2025. Evaluation of the effectiveness of a phytogenic supplement (Alkaloids and Flavonoids) in the control of eimeria spp. in experimentally challenged broiler chickens. Animals 15(6):847.

Hassan A and Mohemmed S, 2024. Novel Effect of Red Grape Seed Extract in Repairing Intercellular Junction in Reticuloendothelial Organs. Pakistan Veterinary Journal 44(3)

Hassan SMH, Zayeda R, Elakany H *et al.*, 2024. Anticoccidial activity of Aloe Vera L eafs' aqueous extract and vaccination against Eimeria tenella:

pathological study in broilers. Veterinary Research Communications 48(1):403-416.
Hayajneh FMF, Abdelqader A, Zakaria H *et al.*, 2024. Drug resistance and coccidiosis affects immunity, performance, blood micronutrients, and intestinal integrity in broiler chickens. International Journal of Veterinary Science 13(1):34-41.
Hegazy SA, Abd ESM, Khorshed MM *et al.*, 2023. Productive and immunological performance of small ruminants offered some medicinal plants as feed additives. International Journal of Veterinary Science 12(1):120-125.
Helmy YA, Taha-Abdelaziz K, Hawwas HAE-H *et al.*, 2023. Antimicrobial resistance and recent alternatives to antibiotics for the control of bacterial pathogens with an emphasis on foodborne pathogens. Antibiotics 12(2):274.
Hou Y, Han B, Lin Z *et al.*, 2024. Effects of Six Natural Compounds and Their Derivatives on the Control of Coccidiosis in Chickens. Microorganisms 12(3):601.
Humayun M, Ayuso JM, Park KY *et al.*, 2022. Innate immune cell response to host-parasite interaction in a human intestinal tissue microphysiological system. Science Advances 8(18):eabm8012.
Iqbal T, Altaf S, Fatima M *et al.*, 2024. A narrative review on effective use of medicinal plants for the treatment of parasitic foodborne diseases. Agrobiological Records 16:79-92.
Jamil M, Aleem MT, Shaukat A *et al.*, 2022. Medicinal plants as an alternative to control poultry parasitic diseases. Life 12(3):449.
Jebessa E, Guo L, Chen X *et al.*, 2022. Influence of Eimeria maxima coccidia infection on gut microbiome diversity and composition of the jejunum and cecum of indigenous chicken. Frontiers in Immunolology 13:994224.
Kalu CM, Ogugua UV, Udeh EL *et al.*, 2024. Plant-microbes' interactions and their roles in bioremediation: A case study of Phragmites australis in acid mine condition. International Journal of Agriculture and Biosciences 13(4):669-682.
Karn SL, Gangwar M, Kumar R *et al.*, 2023. Phage therapy: a revolutionary shift in the management of bacterial infections, pioneering new horizons in clinical practice, and reimagining the arsenal against microbial pathogens. Frontiers in Medicine 10:1209782.
Kasem SM, Mira NM, Helal IB *et al.*, 2024. Prophylactic and therapeutic efficacy of ultrasonicated Rosmarinus officinalis ethanolic extract and its chitosan-loaded nanoparticles against Eimeria tenella infected broiler chickens. Acta Parasitology 69(1):951-999.
Khan MI, Karima G, Khan MZ *et al.*, 2022. Therapeutic effects of saponins for the prevention and treatment of cancer by ameliorating inflammation and angiogenesis and inducing antioxidant and apoptotic effects in human cells. International Journal of Molecular Sciences 23(18):10665.
Kleyn FJ and Ciacciariello M, 2021. Future demands of the poultry industry: will we meet our commitments sustainably in developed and developing economies? Worlds Poultry Science Journal 77(2):267-278.
Kováč J, Slobodníková L, Trajčíková E *et al.*, 2022. Therapeutic potential of flavonoids and tannins in management of oral infectious diseases—a review. Molecules 28(1):158.
Li P, Liu C, Niu J *et al.*, 2022. Effects of dietary supplementation with vitamin A on antioxidant and intestinal barrier function of broilers co-infected with coccidia and Clostridium perfringens. Animals 12(23):3431.
López-Osorio S, Chaparro-Gutiérrez JJ and Gómez-Osorio LM, 2020. Overview of poultry Eimeria life cycle and host-parasite interactions. Frontiers in Veterinary Science 7:384.
Ma D, Wu S, Hou S *et al.*, 2025. Areca catechu L. extract powder ameliorates Eimeria tenella-induced coccidiosis in chicks through anti-inflammatory effects, growth promotion, hematological restoration, and gut microbiota modulation. Poultry Science:105498.
Madlala T, Okpeku M and Adeleke MA, 2021. Understanding the interactions between Eimeria infection and gut microbiota, towards the control of chicken coccidiosis: a review. Parasite 28:48.
Manso T, Lores M and de Miguel T, 2021. Antimicrobial activity of polyphenols and natural polyphenolic extracts on clinical isolates. Antibiotics 11(1):46.
Mares MM, Al-Quraishy S, Abdel-Gaber R *et al.*, 2023. Morphological and molecular characterization of Eimeria spp. infecting domestic poultry Gallus gallus in Riyadh city, Saudi Arabia. Microorganisms 11(3):795.
Martins-Gomes C, Nunes FM and Silva AM, 2024. Natural products as dietary agents for the prevention and mitigation of oxidative damage and inflammation in the intestinal barrier. Antioxidants 13(1):65.
Martins RR, Silva LJG, Pereira AMPT *et al.*, 2022. Coccidiostats and poultry: A comprehensive review and current legislation. Foods 11(18):2738.
Mathis GF, Lumpkins B, Cervantes HM *et al.*, 2024. Coccidiosis in poultry: Disease mechanisms, control strategies, and future directions. Poultry Science 104(5):104663.
Mavrouli M, Mavroulis S, Lekkas E *et al.*, 2023. The impact of earthquakes on public health: A narrative review of infectious diseases in the post-disaster period aiming to disaster risk reduction. Microorganisms 11(2):419.
Mesa-Pineda C, Navarro-Ruíz JL, López-Osorio S *et al.*, 2021. Chicken coccidiosis: from the parasite lifecycle to control of the disease. Frontiers in Veterinary Science 8:787653.
Miranda MR, Vestuto V, Moltedo O *et al.*, 2023. The ion channels involved in oxidative stress-related gastrointestinal diseases. Oxygen 3(3):336-365.
Miska KB, Campos PM, Cloft SE *et al.*, 2024. Temporal changes in jejunal and ileal microbiota of broiler chickens with clinical coccidiosis (Eimeria maxima). Animals 14(20):2976.
Mohlakoana M and Moteetee A, 2021. Southern african soap plants and screening of selected phytochemicals and quantitative analysis of saponin content. Resources 10(10):96.
Mucha P, Skoczyńska A, Małecka M *et al.*, 2021. Overview of the antioxidant and anti-inflammatory activities of selected plant compounds and their metal ions complexes. Molecules 26(16):4886.
Muluneh B, Taye M, Dessie T *et al.*, 2024. Anti-coccidial efficacy of Enteromorpha prolifera polysaccharide in indigenous chickens of Northwest Ethiopia. Veterinary Medicine and Science 10(5):e1524.
Murshed M, Al-Quraishy S, Alghamdi J *et al.*, 2023a. The anticoccidial effect of alcoholic Vitis vinifera leaf extracts on eimeria papillate oocysts isolated in mice in vitro and in vivo. Veterinary Science 10(2):97.
Murshed M, Aljawdah HMA, Mares M *et al.*, 2023b. In vitro: The effects of the anticoccidial activities of Calotropis procera leaf extracts on Eimeria stiedae oocysts isolated from rabbits. Molecules 28(8):3352.
Najmi A, Javed SA, Al Bratty M *et al.*, 2022. Modern approaches in the discovery and development of plant-based natural products and their analogues as potential therapeutic agents. Molecules 27(2):349.
Nguyen BT, Yim D, Flores RA *et al.*, 2024. Large-scale field trials of an Eimeria vaccine induce positive effects on the production index of broilers. Vaccines 12(7):800.
Odden A, Enemark HL, Robertson LJ *et al.*, 2017. Treatment against coccidiosis in Norwegian lambs and potential risk factors for development of anticoccidial resistance—a questionnaire-based study. Parasitology Research 116(4):1237-1245.
Panickar KS and Anderson RA, 2011. Effect of polyphenols on oxidative stress and mitochondrial dysfunction in neuronal death and brain edema in cerebral ischemia. International Journal of Molecular Science 12(11):8181-8207.
Park I, Nam H, Wickramasuriya SS *et al.*, 2023. Host-mediated beneficial effects of phytochemicals for prevention of avian coccidiosis. Frontiers in Immunology 14:1145367.
Pewan SB, Kabantiyok D, Emennaa PE *et al.*, 2025. Advancing Nigerian Indigenous Poultry Health and Production, Use of Probiotics as Viable Alternatives to Antibiotics: A Review. Antibiotics 14(8):846.
Pirintsos S, Panagiotopoulos A, Bariotakis M *et al.*, 2022. From traditional ethnopharmacology to modern natural drug discovery: A methodology discussion and specific examples. Molecules 27(13):4060.
Qaid MM, Al-Mufarrej SI, Azzam MM *et al.*, 2021. Anti-coccidial effect of rumex nervosus leaf powder on broiler chickens infected with eimeria tenella oocyst. Animals 11(1):167.
Rashid S, Hafeez F, Ashraf R *et al.*, 2024. Phytomedicine efficacy and prospects in poultry; a new insight to old anthelmintic resistance. Continental Veterinary Journal 4(1):62-75.
Rieger MM, 2020. Surfactants, Pharmaceutical Dosage Forms. CRC Press pp:211-286.
Ristanti R, Hamid PH, Nugroho HA *et al.*, 2024. Anticoccidial activities of Piper betle L essential oil on Eimeria tenella oocysts. Scientific Reports 14(1):25568.
Rivera-Fernández N, Anacleto-Santos J, Casarrubias-Tabarez B *et al.*, 2022. Bioactive Peptides against Human Apicomplexan Parasites. Antibiotics 11(11):1658.
Rogala-Hnatowska M, Gould G, Mehrotra S *et al.*, 2024. Efficacy and Growth Performance between Two Different Ionophore Coccidiostats (Narasin and Salinomycin) in Broiler Chickens after Challenge with Eimeria spp. Animals 14(18):2750.
Saeed M, Munawar M, Bi JB *et al.*, 2024. Promising phytopharmacology, nutritional potential, health benefits, and traditional usage of Tribulus terrestris L. herb. Heliyon 10(4)

Saeed Z and Alkheraije KA, 2023. Botanicals: A promising approach for controlling cecal coccidiosis in poultry. Frontiers in Veterinary Science 10:1157633.
Saracila M, Panaite TD, Papuc CP *et al.*, 2021. Heat stress in broiler chickens and the effect of dietary polyphenols, with special reference to Willow (Salix spp.) bark supplements-A review. Antioxidants 10(5):686.
Senanayake NS, Boyle L, O'Driscoll K *et al.*, 2025. Effects of season, age and parasite management practices on gastro–intestinal parasites in pigs kept outdoors in Ireland. Irish Veterinary Journal 78(1):12.
Shahzad A, Ammar Tahir MK, Arshad M *et al.*, 2024. Ethnopharmacological use of Moringa oleifera: an updated review. Continental Veterinary Journal 42(65):250-260.
Sharma K, Kaur R, Kumar S *et al.*, 2023. Saponins: A concise review on food related aspects, applications and health implications. Food Chemistry Advances 2:100191.
Shehata AA, Yalçın S, Latorre JD *et al.*, 2022. Probiotics, prebiotics, and phytogenic substances for optimizing gut health in poultry. Microorganisms 10(2):395.
Shetshak MA, Jatau ID, Suleiman MM *et al.*, 2021. In vitro anticoccidial activities of the extract and fractions of Garcinia kola (Heckel h.) against Eimeria tenella Oocyst. Recent Patents on Biotechnology 15(1):76-84.
Singh AK and Kim WK, 2021. Effects of dietary fiber on nutrients utilization and gut health of poultry: a review of challenges and opportunities. Animals 11(1):181.
Snyder RP, Guerin MT, Hargis BM *et al.*, 2021. Restoration of anticoccidial sensitivity to a commercial broiler chicken facility in Canada. Poultry Science 100(2):663-674.
Song H-Y, Deng M-L, Yang J-F *et al.*, 2023. Transcriptomic, 16S ribosomal ribonucleic acid and network pharmacology analyses shed light on the anticoccidial mechanism of green tea polyphenols against Eimeria tenella infection in Wuliangshan black-boned chickens. Parasites and Vectors 16(1):330.
Sweidan RW, Hayajneh FM, Awabdeh SA *et al.*, 2025. Herbal Medicine: A Natural Alternative Treatment of Avian Coccidiosis. International Journal of Agriculture and Bioscience 14(5):811-817.
Tahir F, Fatima F, Fatima R *et al.*, 2023. Fruit peel extracted polyphenols through ultrasonic assisted extraction: A review. Agrobiological Records 15: 1-12.
Tchodo FG, Dakpogan HB, Sanvee S *et al.*, 2024. The anticoccidial in vitro effects and antioxidant properties of several plants traditionally used for coccidiosis in Togo. Veterinary Science 11(8):345.
Thomas E, Stewart LE, Darley BA *et al.*, 2021. Plant-based natural products and extracts: Potential source to develop new antiviral drug candidates. Molecules 26(20):6197.
Tian Y, Xu W, Guang C *et al.*, 2024. Glycosylation of flavonoids by sucrose- and starch-utilizing glycoside hydrolases: A practical approach to enhance glycodiversification. Critical Reviews in Food Science and Nutrition 64(21):7408-7425.
Vaou N, Stavropoulou E, Voidarou C *et al.*, 2022. Interactions between medical plant-derived bioactive compounds: Focus on antimicrobial combination effects. Antibiotics 11(8):1014.
Vinelli V, Biscotti P, Martini D *et al.*, 2022. Effects of dietary fibers on short-chain fatty acids and gut microbiota composition in healthy adults: a systematic review. Nutrients 14(13):2559.
Wang H, Chen L, Yang B *et al.*, 2023. Structures, sources, identification/ quantification methods, health benefits, bioaccessibility, and products of isorhamnetin glycosides as phytonutrients. Nutrients 15(8):1947.
Wang P, Jia Y, Han Y *et al.*, 2021. Eimeria acervulina Microneme protein 3 inhibits apoptosis of the chicken duodenal epithelial cell by targeting the casitas B-lineage lymphoma protein. Frontiers in Veterinary Science 8:636809.
Wickramasuriya SS, Park I, Lee K *et al.*, 2022. Role of physiology, immunity, microbiota, and infectious diseases in the gut health of poultry. Vaccines 10(2):172.
Wickramasuriya SS, Park I, Lee Y *et al.*, 2023. Effect of dietary organic selenium on growth performance, gut health, and coccidiosis response in broiler chickens. Animals 13(9):1560.
Xu L, Xiang Q, Li M *et al.*, 2022. Pathogenic effects of single or mixed infections of Eimeria mitis, Eimeria necatrix, and Eimeria tenella in chickens. Veterianry Science 9(12):657.
Zaheer T, Abbas RZ, Imran M *et al.*, 2022. Vaccines against chicken coccidiosis with particular reference to previous decade: progress, challenges, and opportunities. Parasitology Research 121(10):2749-2763.
Zeeshan M, Pandey R, Subudhi AK *et al.*, 2021. Protein phosphatase 1 regulates atypical mitotic and meiotic division in Plasmodium sexual stages. Communications Biolology 4(1):760.
Zhang C, Liu Y, Liu X *et al.*, 2023. Comprehensive review of recent advances in chiral A-ring flavonoid containing compounds: Structure, bioactivities, and synthesis. Molecules 28(1):365.
Zhang Z, Xu P, Liu C *et al.*, 2024. Effect of tannic acid on antioxidant function, immunity, and intestinal barrier of broilers co-infected with coccidia and clostridium perfringens. Animals 14(6):955.
Zhao D, Suo J, Liang L *et al.*, 2024. Innovative prevention and control of coccidiosis: targeting sporogony for new control agent development. Poultry Science 103(12):104246.
Zhu Y, Liu D, Wang L *et al.*, 2025. Observations of the Fine Structural Changes Associated with Merogony and Gametogony in Eimeria necatrix and Localization of Two Gametocyte Proteins. Microorganisms 13(5):1135.