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ADVANCEMENTS IN TECHNOLOGY FOR DIAGNOSING AND CONTROLLING COCCIDIOSIS IN POULTRY: A REVIEW OF THE EIMERIA GENUS

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ABSTRACT

Coccidiosis accounts for significant economic losses in poultry production, with a global impact estimated at $3 billion annually. The spread of the disease is facilitated by typical conditions of intensive production systems, further exacerbated by climate changes that increase the frequency of outbreaks in new regions. Traditional control methods, relying on anticoccidial drugs, have been compromised by the development of resistance, driving the adoption of live attenuated and recombinant vaccines. Advances in molecular diagnostics, such as real-time PCR and next-generation sequencing, provide greater precision in species identification and disease control. The economic impact, etiology, epidemiology,

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and new approaches in the diagnosis and control of coccidiosis highlight future challenges, including anticoccidial resistance and the pressing need for more sustainable solutions.

Keywords: Poultry Production. Coccidia. Antimicrobial Resistance. Attenuated Vaccines. Real-Time PCR.

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INTRODUCTION

Coccidiosis, caused by protozoa of the genus Eimeria, is a pressing issue in poultry production. These intracellular parasites attack the intestinal tract of birds, resulting in severe lesions that impair nutrient absorption and feed efficiency and often lead to mortality. With estimated global economic losses exceeding $10 billion annually, coccidiosis poses a critical challenge to the sustainability of the poultry industry (Attree et al., 2021). The losses include direct impacts, such as reduced weight gain and increased mortality, as well as indirect costs related to medications, vaccines, and biosecurity measures (Mesa-Pineda et al., 2021).

The complex life cycle of *Eimeria* spp. Facilitates its persistence in the environment and transmission between flocks, particularly in intensive production systems where high population density and inadequate management practices favor the parasite's spread (Yu & Heo, 2021). Additionally, climate change has expanded the geographical range of coccidiosis, with outbreaks reported in regions previously less affected (Madlala et al., 2021).

Although anticoccidial drugs have historically been the primary tool for controlling coccidiosis, their efficacy is decreasing due to the development of resistance in several *Eimeria* species. This phenomenon has driven the search for alternative approaches, such as vaccines and immunomodulatory dietary supplements (Lee et al., 2022). The emergence of promising technologies, including using nanoparticles to encapsulate anticoccidial drugs and minimize environmental residues, offers hope for the future of disease management (Baron et al., 2022).

At the same time, studies on the interactions between coccidiosis and the gut microbiome have opened new pathways for disease management. The gut microbiome plays a crucial role in modulating the host immune response and can influence the severity of coccidiosis. Strategies involving probiotics and phytogenics, which can manipulate the gut microbiome, are emerging as sustainable methods to reduce oocyst viability in the environment and enhance intestinal health and immune responses in poultry (Saeed & Alkheraije, 2023).

This review examines the latest advancements in diagnosing, controlling, and preventing coccidiosis, highlighting emerging technologies and integrated management practices that aim to mitigate the disease's economic and environmental impacts.

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ECONOMIC IMPACT OF COCCIDIOSIS ON POULTRY PRODUCTION

Coccidiosis is one of the most significant economic threats to poultry production, causing substantial losses associated with reduced productivity, medication and vaccine costs, mortality, and decreased feed conversion rates. Recent estimates suggest that the global economic losses attributed to coccidiosis exceed $10 billion annually, significantly impacting intensive production systems (Attree et al., 2021).

A study conducted in Indonesia estimated the direct and indirect losses related to coccidiosis at approximately Rp 3.37 trillion (around $236 million), highlighting the importance of implementing effective disease control programs in this region (Pawestri et al., 2020). In the United Kingdom, an updated analysis indicated that the cost of coccidiosis to the broiler industry reached £99.2 million in 2016, showing a significant increase compared to previous estimates due to the industry's growth and the rising resistance to anticoccidial drugs (Blake et al., 2020). These regional studies underscore the global economic impact of coccidiosis on poultry production.

Furthermore, a study in Pakistan revealed that losses due to coccidiosis and associated infections exceeded $2.7 million annually in broiler chickens, with a significant portion of these losses linked to reduced weight gain and feed efficiency (Rashid et al., 2019).

These data underscore the need for integrated control strategies that combine the rational use of medications with management and biosecurity practices. By implementing these strategies, we can mitigate the economic impact of coccidiosis on global poultry production, empowering us to combat this significant threat.

ETIOLOGY AND LIFE CYCLE

The genus *Eimeria* includes more than a dozen species that affect poultry, with the most pathogenic being *Eimeria tenella*, *Eimeria maxima*, *Eimeria acervulina*, *Eimeria necatrix*, *Eimeria brunetti*, and *Eimeria mitis*. Each species exhibits specific tropism for different regions of the gastrointestinal tract (small and large intestines), causing lesions that range from mild to severe depending on the species and parasite load (Ogedengbe et al., 2011; Blake et al., 2020; Cervantes et al., 2020).

Infection by *Eimeria* occurs when the host ingests sporulated oocysts. Within the gastrointestinal tract, these oocysts release sporozoites, which invade epithelial cells and initiate the asexual reproduction cycle (schizogony). The destruction of epithelial cells

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during this phase is the primary cause of clinical symptoms, such as diarrhea, dehydration, and, in severe cases, mortality. Following schizogony, the sexual reproduction phase (gametogony) occurs, forming new oocysts shed into the environment via feces (Shirley et al., 2005).

EPIDEMIOLOGY

Coccidiosis is a widely prevalent disease, especially in intensive production systems where environmental conditions favor the sporulation of oocysts (Long & Joyner, 1984). High population density and direct contact with contaminated feces are the primary factors facilitating Eimeria spp. Dissemination on poultry farms. Studies indicate that virtually all broiler operations are exposed to *Eimeria* infections at some point in the production cycle (Peek & Landman, 2011).

In addition to environmental conditions, coccidiosis outbreaks are more frequent in warm and humid climates, which favor oocyst sporulation. Oocysts' resilience to adverse conditions, such as desiccation and extreme temperatures, complicates infection control, necessitating continuous biosecurity measures, including rigorous disinfection of facilities and flock rotation. Recently, resistance to anticoccidial drugs and the emergence of *Eimeria* variants that evade traditional diagnostic methods have become additional challenges to effective coccidiosis control (Dalloul & Lillehoj, 2006).

Climate change, characterized by more extended periods of warm and humid conditions, can potentially exacerbate the impact of coccidiosis, resulting in more frequent outbreaks in previously less affected regions. These changes require constant monitoring and the development of new control technologies, such as advanced vaccines and rapid molecular diagnostics (Blake & Tomley, 2014).

DIAGNOSIS AND LABORATORY TESTING

Traditionally, the diagnosis of coccidiosis has relied on observing clinical signs and detecting oocysts in feces through flotation or centrifugation methods using saturated sugar or salt solutions. While helpful, these methods have limitations in identifying subclinical infections and precisely differentiating the various *Eimeria* species, essential for determining disease severity and appropriate treatment (Mohammed et al., 2023).

Necropsies of affected birds remain an essential diagnostic tool, revealing characteristic lesions in the gastrointestinal tract indicative of *Eimeria* infection. However,

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the accuracy of this method can be compromised by the difficulty of identifying mixed infections and adequately quantifying parasite loads (Balestrin et al., 2022).

In recent years, technological advancements have revolutionized the diagnosis of coccidiosis. Molecular tools such as real-time PCR and Loop-Mediated Isothermal Amplification (LAMP) enable rapid and specific detection of *Eimeria* species, identifying mixed infections and quantifying parasite loads with greater sensitivity (Loo et al., 2019).

Integrating molecular methods with emerging technologies such as Next-Generation Sequencing (NGS) provides even more comprehensive diagnostics. These techniques detect genetic mutations associated with drug resistance and allow detailed characterization of host-parasite interactions, optimizing management and control strategies (Yu et al., 2023).

These advancements underscore the growing importance of precise diagnostics for effective coccidiosis control, particularly in intensive production systems where animal health is directly linked to economic and environmental sustainability.

CONTROL AND PREVENTION

Historically, coccidiosis control has been primarily based on using anticoccidial drugs, including ionophores and synthetic chemicals. These medications have been effective in reducing parasite loads and preventing clinical outbreaks. However, prolonged use has led to resistance in various *Eimeria* species, prompting the poultry industry to seek more sustainable and effective disease management strategies (Ahmad et al., 2023).

Live attenuated and recombinant vaccines have emerged as critical tools for controlling coccidiosis in intensive production systems. These vaccines enable birds to develop immunity without the detrimental effects of clinical disease. In particular, DNA-based and antigen-specific vaccines, such as transgenic formulations, have shown the potential to improve efficacy and protective immune responses (Ziam et al., 2020). Additionally, strategies involving herbal extracts and phytogenics are being explored as sustainable alternatives due to their antioxidant and immunomodulatory properties (Saeed & Alkheraije, 2023).

The development of vaccines and other interventions requires a detailed understanding of the protective role of local immune responses in the intestine and the identification of specific molecules that mediate anticoccidial activity. Emerging

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technologies, such as nanocapsules for encapsulating anticoccidial drugs, have effectively reduced oocyst excretion and minimized environmental residues (Baron et al., 2022).

Management practices, including frequent litter changes, adequate ventilation, and facility cleaning, remain essential for coccidiosis control. Additionally, probiotics have gained attention for enhancing immune responses and reducing oocyst viability, complementing existing control strategies (Mohsin et al., 2021).

RESISTANCE TO ANTICOCCIDIAL DRUGS

Resistance to anticoccidial drugs is one of the most significant challenges in controlling coccidiosis in intensive production systems. A study in Algeria reported complete resistance to monensin and robenidine and partial resistance to salinomycin and narasin-nicarbazin, indicating cross-resistance development in *Eimeria* populations (Ferdji et al., 2021). In Brazil, resistance to drugs such as amprolium and dinitolmide has also been documented in several isolates of *Eimeria tenella* and *Eimeria acervulina* (Chapman et al., 2014).

Recent studies indicate that multidrug resistance is shared across various regions. In Colombia, a survey detected a high prevalence of *Eimeria* spp. in farms and limited efficacy of some drugs against the isolated strains (Mesa et al., 2021). Coccidiosis vaccines containing drug-sensitive strains in Canada demonstrated improved sensitivity after vaccine introduction. However, factors such as litter management between flocks may limit the long-term effectiveness of this approach (Snyder et al., 2020).

These findings highlight the need for constant monitoring and new control strategies, including the development of advanced vaccines and the rational use of existing medications. Additionally, anticoccidial sensitivity testing on *Eimeria* strains in commercial vaccines has shown that these strains remain susceptible to most drugs tested, reinforcing the potential of vaccines in managing resistance (Mathis et al., 2021).

INTERACTION OF COCCIDIOSIS WITH THE INTESTINAL MICROBIOME

The interaction between coccidiosis and the intestinal microbiome has been increasingly studied. Infections by Eimeria spp significantly alter the bacterial composition in the gut, affecting poultry intestinal health. For example, *Eimeria tenella* has been associated with reduced beneficial bacteria such as *Lactobacillus* and increased opportunistic

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pathogens like *Enterococcus* and *Streptococcus*, exacerbating disease damage (Chen et al., 2020).

Modulating the microbiome through probiotics has shown promising results in controlling coccidiosis. Recent studies reveal that probiotics can enhance immune responses, reduce oxidative stress, and stimulate microbial balance, decreasing oocyst viability and improving gut health. In one study, the probiotic *Lactobacillus plantarum P8* significantly reduced mortality and oocyst excretion while improving intestinal integrity in chickens infected with *Eimeria tenella* (Wang et al., 2021).

Additionally, supplementation with probiotics such as *Bacillus subtilis* has demonstrated positive effects on gut microbiota modulation, increasing beneficial bacteria abundance and reducing the impact of *Eimeria* spp. on growth performance and intestinal health in poultry (Memon et al., 2022).

These findings underscore the importance of the microbiome as a therapeutic target for managing coccidiosis, particularly in production systems seeking to reduce chemical drug use and optimize animal health.

CHALLENGES AND FUTURE PERSPECTIVES IN COCCIDIOSIS CONTROL

The complexity of the *Eimeria* life cycle and its high environmental survival capacity make controlling the disease challenging, particularly in intensive production systems (Attree et al., 2021). The challenges in coccidiosis control extend beyond drug resistance. Climate change alters disease occurrence patterns, with more frequent outbreaks in previously less-affected regions, increasing pressure to develop more effective and sustainable control strategies (Fabia et al., 2021).

Third-generation vaccines, such as DNA and transgenic, are emerging as promising alternatives to immunize birds more efficiently and durably. For instance, transgenic vaccines have demonstrated the potential to increase protective efficacy by combining multiple specific antigens (Fatoba & Adeleke, 2020).

Additionally, new approaches, such as the use of polymeric nanocapsules to encapsulate anticoccidial drugs like toltrazuril, have proven effective in reducing oocyst excretion and intestinal lesions while minimizing drug residues in meat and the environment (Baron et al., 2022).

The use of biotechnology, including the identification of specific *Eimeria* antigens and the development of recombinant vaccines, is expanding. New diagnostic methods, such as

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Next-Generation Sequencing (NGS), are being integrated into control programs to provide more precise and rapid pathogen identification, facilitating more effective interventions (Ziam et al., 2020).

The future of coccidiosis control will depend on combining these technological innovations with robust management practices and enhanced biosecurity strategies. Additionally, methods such as using phytogenic supplements, including botanical compounds with antioxidant and immunomodulatory properties, may complement these technological approaches for integrated disease control (Saeed & Alkheraije, 2023).

FINAL CONSIDERATIONS

Advances in diagnostic methods, such as real-time PCR and next-generation sequencing, have proven to be essential for the early and accurate detection of infections, enabling better managing the parasite load in birds and controlling outbreaks. Live attenuated, recombinant, and DNA vaccines have offered effective alternatives, reducing dependence on anticoccidials and minimizing the impact of drug resistance. Adopting these vaccines, combined with integrated management practices, such as rigorous maintenance of hygiene in facilities, probiotics, and flock rotation, is essential for effectively controlling coccidiosis and, is critical for effectively controlling coccidiosis and promoting bird health. The combination of new diagnostic technologies with sustainable control strategies has contributed to the reduction of economic losses and the improvement of animal welfare in poultry farming. However, as resistance to anticoccidials continues to expand and climate conditions change, the continued development of innovative solutions will be crucial to ensure productive efficiency and sustainability in the poultry sector.

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