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PREVALENCE OF EIMERIA SPP. IN BIRDS: CHALLENGES AND SUSTAINABLE CONTROL STRATEGIES

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ABSTRACT
Coccidiosis, caused by protozoa of the genus Eimeria, is one of the major threats to poultry farming, with high prevalence and significant economic impacts. This study reviews the prevalence of Eimeria spp. in birds, addressing regional differences, farming systems, and diagnostic methodologies, such as microscopy and multiplex PCR. Resistance to anticoccidials and environmental challenges underscores the need for effective management strategies. Emerging solutions, including vaccines, probiotics, and strict biosecurity practices, have shown potential to mitigate the impacts of coccidiosis. However, the lack of continuous monitoring and studies in underexplored regions limits understanding of the disease's epidemiology. Investment in representative research and advanced technologies is crucial for developing sustainable strategies and ensuring a more resilient poultry industry.

Keywords: Coccidiosis. Eimeria Spp. Poultry Farming. Wild Birds. Anticoccidial Resistance.

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INTRODUCTION

Coccidiosis, caused by protozoa of the genus *Eimeria*, is one of the most significant parasitic diseases affecting global poultry production, resulting in substantial economic losses. In Brazil, poultry farming is central to agribusiness, accounting for a large share of animal protein production. Coccidiosis affects approximately 90% of broiler farms, with *Eimeria acervulina*, *E. maxima*, and *E. tenella* being the most prevalent species. These infections significantly reduce bird weight gain and feed conversion efficiency, increasing production costs and reducing the sector's competitiveness (Moraes et al., 2015; Choi et al., 2021).

Global studies estimate that coccidiosis causes annual losses exceeding USD 3 billion, considering the costs of chemoprophylaxis, treatment, and decreased production performance. In Brazil, each infected broiler flock can incur losses of approximately €3,162, directly affecting feed conversion and bird mortality rates (Györke et al., 2016). In intensive production systems, high population densities favor oocyst dissemination, exacerbating infection severity (Toledo et al., 2011).

Inadequate management of coccidiosis and prolonged use of synthetic anticoccidials has led to resistance in various *Eimeria* species, necessitating higher dosages and increasing chemical residues in the environment. Sustainable alternatives, such as vaccines and probiotics, have proven effective in reducing oocyst shedding and improving intestinal health, contributing to more sustainable production systems (Nguyen et al., 2021; Ahmad et al., 2023).

Additionally, climate change, with rising temperatures and humidity, favors oocyst survival in the environment, exacerbating coccidiosis prevalence. Strategies such as controlled ventilation and intensive hygiene are essential to mitigate these impacts, requiring control practices to adapt to new environmental conditions (Balestrin et al., 2021). Combining chemical control with sustainable alternatives is critical to addressing anticoccidial resistance and the ecological challenges of intensive broiler production.

This review's objective is to provide a comprehensive analysis of the prevalence of *Eimeria spp.* in birds, with emphasis on different regions, farming systems, and diagnostic methodologies. It will also discuss the economic and health implications and emerging coccidiosis prevention strategies.

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MATERIALS AND METHODS

This review employed a systematic search strategy to identify relevant studies on the prevalence of Eimeria spp. in broiler chickens and captive wild birds. It focused on Brazil and compared it with international data. The search was conducted across academic databases, including PubMed, Scopus, Google Scholar, and Web of Science.

Search terms included combinations of the following descriptors in English and Portuguese, using Boolean operators (AND, OR): "Eimeria spp. AND prevalence AND broiler chickens"; "Eimeria spp. AND prevalence AND wild birds"; "Coccidiosis AND Eimeria AND Brazil"; "Prevalence of Eimeria in poultry AND wild birds"; "Eimeria spp. AND control strategies AND vaccination AND anticoccidial drugs"; "Coccidiose AND frangos de corte AND manejo sanitário"; "Coccidiose AND aves silvestres AND Brasil"; "Eimeria spp. AND wild birds AND molecular detection."

Studies were eligible for inclusion if they met the following criteria:

Target Population: Studies involving broiler chickens in commercial farming systems, free-range chickens, and captive wild birds in Brazil, as well as comparative international studies.

Study Design: Observational (cross-sectional or longitudinal) and experimental studies reporting the prevalence of Eimeria spp. or investigating control and prevention strategies for coccidiosis.

Diagnostic Methods: Studies employ traditional methods (microscopy, flotation) and molecular approaches (PCR, multiplex PCR) for detecting Eimeria.

Peer-Reviewed Publication: Only studies published in peer-reviewed scientific journals were included.

Studies were excluded if they:

Did not provide data on the prevalence of Eimeria spp. or control strategies.

Focused on other bird species or conditions unrelated to coccidiosis.

Extracted data were organized and analyzed qualitatively. Emphasis was placed on comparing the prevalence of Eimeria spp. Across Brazilian regions and other countries and identifying variations in diagnostic methodologies and control strategies. A comparative analysis was conducted to pinpoint trends and gaps in the literature, highlighting challenges and advancements in coccidiosis management.

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RESULTS AND DISCUSSION

A recent study conducted in Santa Catarina, Brazil, highlighted the influence of ventilation systems on the prevalence of *Eimeria spp.* Balestrin et al. (2021) compared positive and negative pressure ventilation systems, identifying an overall prevalence of 90.6%, with *E. acervulina*, *E. maxima*, and *E. tenella* as the most frequent species. The results suggest that adopting appropriate environmental management practices, such as selecting optimal ventilation systems, can significantly reduce infection rates and improve intestinal health in birds. Furthermore, the study employed an integrated diagnostic approach, combining macroscopy, histopathology, and PCR, enabling more precise and comprehensive detection, particularly in cases of mixed infections (Balestrin et al., 2021).

The prevalence of *Eimeria spp.* in broiler chickens has been widely documented across different regions worldwide (Figures 1 and 2). In Sudan, Alzib and Abdelnabi (2017) reported a prevalence of 5.5% for *E. tenella* and *E. acervulina*. In Nigeria, Nana-Mariam et al. (2023) found a prevalence of 36.3% for mixed infections. Györke et al. (2013) detected E. acervulina in 91% of samples in Romania. Matsubayashi et al. (2020) used molecular tools to reveal a high prevalence of E. brunetti in Japan. Similarly, Chere et al. (2022) identified seven *Eimeria* species in Ethiopia, while Jordan et al. (2018) documented mixed infections in all farms surveyed in Trinidad, underscoring global patterns.

Studies in North America have shown that intensive production systems widely employ vaccines and anticoccidials, resulting in moderate prevalences of *E. acervulina* and *E. maxima*. However, increasing medication resistance remains a significant concern (Blake & Tomley, 2014). In Canada, biosecurity strategies have reduced outbreaks in commercial farms, although small-scale operations continue to require attention.

In Asia, recent studies from regions such as Anhui Province, China, reported prevalences of 87.75%, with *E. tenella* (80.67%) being the predominant species, followed by *E. necatrix* and *E. maxima* (Huang et al., 2017). Similarly, in Zhejiang, up to 30.7% of prevalences were observed in commercial systems, highlighting significant challenges related to anticoccidial resistance (Lan et al., 2017). In India, prevalences exceeding 79% were reported in northern farms, with a notable diversity in genetic variants of detected species (Kumar et al., 2015).

In Western Europe, countries like France and Germany report lower prevalences in organic systems due to improved management practices and lower flock densities.

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However, In Eastern Europe, E. acervulina was detected in 91% of cases, with common mixed infections (Györke et al., 2013).

In Oceania, a comprehensive study in Australia revealed prevalences of *Eimeria spp.* in 98% of commercial farms and 81% of backyard systems. The study highlighted differences in predominant species between these systems and noted the potential for backyard flocks to serve as parasite reservoirs (Godwin & Morgan, 2015).

In Africa, aside from the previously mentioned data from Sudan and Nigeria, studies in countries such as Ghana, Tanzania, and Zambia reported the presence of all seven known *Eimeria* species. These high prevalences were associated with significant economic losses in small-scale, semi-intensive systems (Fornace et al., 2013).

This global perspective emphasizes the multifaceted challenges posed by *Eimeria spp: infections* and the need for region-specific strategies to manage coccidiosis effectively.

Figure 1. Global distribution of mixed *Eimeria spp.* Infections in broiler chickens, showing prevalence variations across different regions

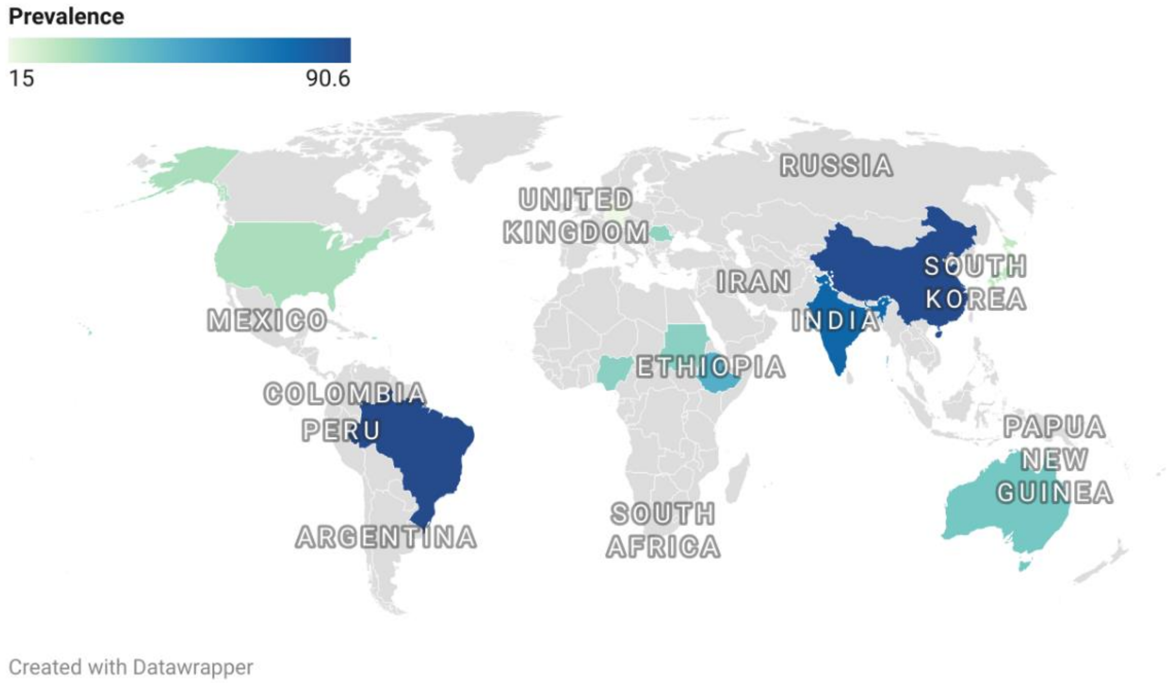

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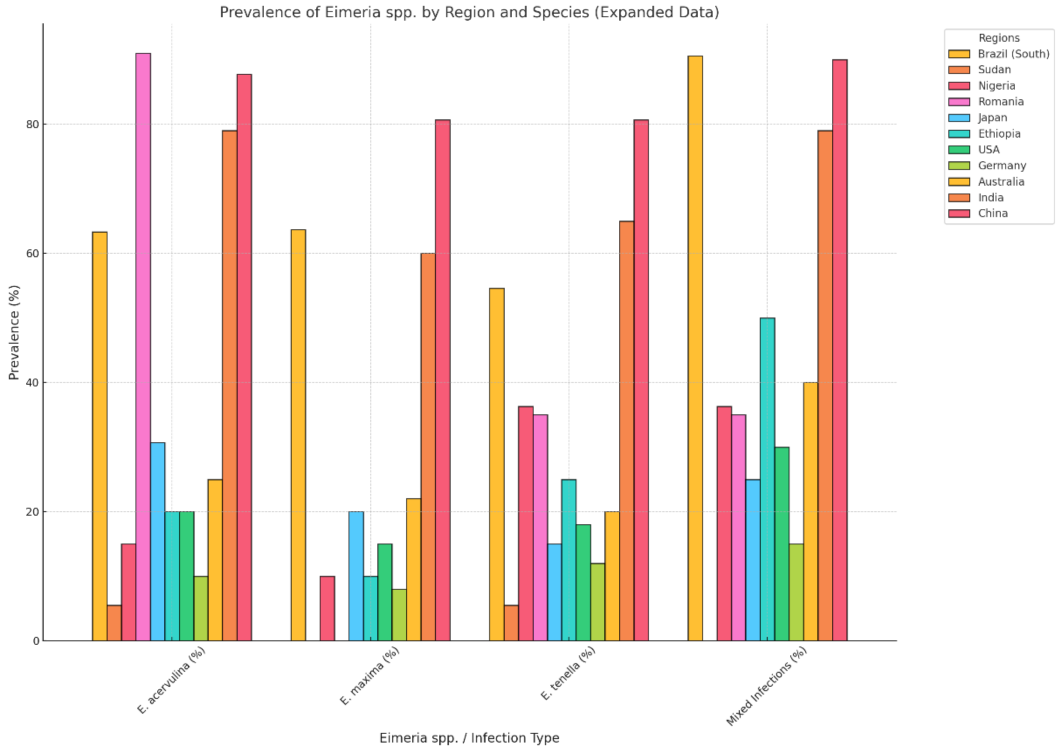
Figure 2. Prevalence of mixed *Eimeria spp.* Infections in broiler chickens across different regions, highlighting the highest rates in Brazil, India, and China



CRITICAL DISCUSSION OF METHODOLOGIES

Studies on the prevalence of *Eimeria spp.* in Brazil have employed various methodologies, from traditional techniques to advanced methods like multiplex PCR. Each approach has its advantages and limitations, which directly impact the accuracy of results and the generalizability of findings (Figure 2).

The use of multiplex PCR, exemplified by the study of Moraes et al. (2015), represents a significant advance in diagnostic accuracy. This technique enables the simultaneous detection of multiple *Eimeria* species with high sensitivity and specificity, which is crucial for identifying mixed infections. Globally, molecular methods such as PCR have been widely used in regions like China, where Huang et al. (2017) reported prevalences exceeding 87% in broiler farms. However, the relatively high cost of these advanced technologies and the requirement for well-equipped laboratories limit their applicability in many rural areas of Brazil and developing countries like India (Kumar et al., 2015). This scenario hampers the implementation of comprehensive coccidiosis control programs nationally and globally.

Conversely, traditional diagnostic methods, such as microscopy and flotation techniques, remain widely used, particularly in studies conducted in regions with fewer

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technological resources. For instance, Amaral and Otutumi (2013) employed microscopy to detect *Eimeria spp.* in broilers in Paraná. While effective for identifying clinical infections, these methods have significant limitations. Their reduced sensitivity can underestimate subclinical infections, which, as highlighted by Gazoni et al. (2019), are up to 11.25 times more prevalent than clinical cases. In Sub-Saharan Africa, Fornace et al. (2013) reported that exclusive reliance on traditional methods often obscures the true extent of coccidiosis, especially in extensive farming systems.

Moreover, traditional methods struggle to detect mixed infections. Studies like Amaral and Otutumi (2013), which relied on microscopy, may fail to identify the simultaneous presence of multiple *Eimeria* species. In contrast, studies using molecular techniques, such as Moraes et al. (2015), demonstrated a high prevalence of mixed infections, particularly of *E. maxima* and *E. acervulina*, underscoring the importance of more sensitive methods to understand coccidiosis epidemiology.

Geographical representation and sample size are additional challenges. In Brazil, many studies are based on samples from specific locations, such as Silva et al. (2022) in the Northeast, which detected E. necatrix and E. mitis prevalences in free-range chickens. In contrast, international studies like Yang and Shim (2016) in South Korea employed broader samples covering multiple regions, providing a more comprehensive and representative view. Similarly, studies in Australia by Godwin and Morgan (2015) combined molecular analyses with climatic data to identify seasonal infection patterns in an underexplored area in Brazil.

The lack of longitudinal studies further limits the understanding of infection dynamics in Brazil. While helpful in providing a snapshot of prevalence at a specific moment, cross-sectional studies do not capture seasonal fluctuations or changes associated with environmental and management variations. In comparison, longitudinal studies in Western Europe and Australia have offered valuable insights into how climatic and seasonal factors influence the transmission and persistence of *Eimeria spp.* (Godwin & Morgan, 2015; Györke et al., 2013).

Another critical aspect is the standardization of control strategies. Studies in Brazil, such as Balestrin et al. (2020), analyzed biosecurity measures like lime in poultry litter, while others, like Costa et al. (2023), explored the use of vaccines and feed additives. However, the lack of standardized protocols complicates direct comparisons between control strategies. Globally, collaborative initiatives, such as research networks within the

European Union, have sought to standardize protocols to compare the effectiveness of different approaches.

Finally, resistance to anticoccidial drugs is a growing concern in global poultry production. Studies in Asian countries, such as China and India, have linked intensive anticoccidial use to increased resistance, an issue also beginning to emerge in Brazil. This underscores the need for investment in sustainable strategies, such as vaccines and probiotics, to reduce reliance on medications and effectively and durably control coccidiosis.

GLOBAL COMPARISONS AND REGIONAL IMPLICATIONS

The prevalence of *Eimeria spp.* in broiler chickens in Brazil aligns with international data, reflecting the global complexity of coccidiosis (Figure 3). In South Korea, Yang and Shim (2016) identified *E. acervulina* in 96.4% of flocks and *E. tenella* in 81.8%, highlighting the high prevalence of mixed infections. Similar patterns were observed in Romania, where Györke et al. (2013) reported mixed infections of *E. acervulina* and *E. tenella* in 35% of samples, emphasizing the significance of these species in global poultry farming. In South Africa, Fatoba et al. (2020) documented mixed infections in 59.5% of flocks, with *E. maxima* and *E. tenella* predominant, demonstrating the wide distribution of multiple-species infections.

In Brazil, studies like Balestrin et al. (2021) confirm that mixed infections are a significant challenge, with *E. acervulina*, *E. maxima*, and *E. tenella* being the most frequently detected species. Mixed infections complicate effective management due to variability in responses to control and prevention strategies, particularly in intensive systems. To mitigate these impacts, introducing biosecurity measures, such as applying lime to poultry litter, has proven effective in reducing the prevalence of *E. maxima* and *E. tenella* (Balestrin et al., 2021).

Comparisons between Brazilian and international data reveal that factors such as climate, management practices, and access to technology directly influence the prevalence and control of *Eimeria spp.* In tropical countries like Brazil and Nigeria, high humidity and elevated temperatures favor oocyst survival and dissemination, necessitating strict management practices, such as optimized ventilation and continuous hygiene. Studies in Nigeria, like Nana-Mariam et al. (2023), emphasize that mixed infections are prevalent in semi-intensive systems, suggesting the need to tailor management strategies to different production systems.

Conversely, in regions like North America and Western Europe, prevalences are more controlled due to the systematic use of vaccines and advanced biosecurity strategies. In the United States, for instance, the introduction of multivalent vaccines has significantly reduced mixed infection prevalence, while in Germany, organic production systems with lower flock densities contribute to lower overall prevalences of *Eimeria spp.* (Blake & Tomley, 2014). In Oceania, studies in Australia by Godwin and Morgan (2015) revealed that combined strategies, such as enhanced biosecurity and molecular monitoring, were crucial in reducing infection incidence.

Additionally, the heterogeneity in management and control practices across different Brazilian regions highlights the need for a localized approach. For instance, in the Northeast, Silva et al. (2022) identified *E. necatrix* as one of the predominant species, in contrast to the South, where *E. acervulina* is more prevalent (Balestrin et al., 2021; Silva et al., 2022). This regional variability underscores the importance of adapting control strategies to local conditions, considering factors such as flock density, climate, and access to diagnostic technologies.

Finally, global comparisons reinforce the need for investments in collaborative research to standardize management and control protocols. The experience of research networks within the European Union, which promote the exchange of data and strategies between countries, could serve as a model for similar initiatives in Brazil and Latin America, enhancing the effectiveness of coccidiosis control efforts and reducing its economic and productive impacts.

STUDY LIMITATIONS

While this review provides a comprehensive overview of the prevalence of *Eimeria spp.* in broiler chickens and wild birds in Brazil, several significant limitations must be acknowledged:

METHODOLOGICAL HETEROGENEITY

The reviewed studies employed various diagnostic techniques, from traditional methods such as microscopy and flotation to advanced molecular approaches like multiplex PCR and genetic sequencing. This methodological diversity complicates direct comparisons of results, particularly regarding detecting mixed and subclinical infections. For example, studies like Amaral and Otutumi (2013), which used microscopy, may underestimate mixed infections that are more detectable using molecular techniques, as Moraes et al. (2015) observed. Globally, this heterogeneity is also a challenge in international studies, such as those conducted in Asia and Europe (Györke et al., 2013; Huang et al., 2017), where standardizing methodologies has become a recent objective.

LIMITED GEOGRAPHIC COVERAGE

Most studies focus on Brazil's southern and southeastern regions, such as those conducted in Paraná (Amaral & Otutumi, 2013; Balestrin et al., 2021) and Santa Catarina. Data from other areas, such as the North and Central-West, are scarce, limiting the understanding of *Eimeria spp.* Prevalence in different ecosystems and management systems. This gap is particularly relevant in areas like the Amazon, where environmental conditions could significantly influence coccidiosis epidemiology. International studies in tropical regions, like Sub-Saharan Africa (Nana-Mariam et al., 2023), suggest that local factors, such as climate and flock density, play a crucial role that remains underexplored in Brazil.

LACK OF LONGITUDINAL STUDIES

Most reviewed research adopts a cross-sectional design, providing only a "snapshot" of *Eimeria spp—Prevalence* at a specific moment. Longitudinal studies are needed to capture seasonal variations and infection dynamics over time. For instance, Godwin and Morgan (2015) used longitudinal approaches to correlate Eimeria spp in Australia. Outbreaks with climatic changes and management practices. This type of analysis is still rare in Brazil but is essential for informing adaptable and data-driven control strategies.

INSUFFICIENT DATA ON WILD BIRDS

Although including wild birds in this review offers valuable insights into potential zoonotic interactions, few studies deeply investigate the relationship between *Eimeria spp—prevalence* in domestic and wild birds, particularly in areas where these species coexist. Snak et al. (2014) reported significant prevalences of *Eimeria spp.* in captive birds in Paraná, but little is known about how these populations might act as reservoirs for commercial farms. Globally, reviews like Ortúzar-Ferreira et al. (2019) highlight the need for more studies on *Eimeria spp—biodiversity* in wild birds and its impact on production systems.

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LIMITED FOCUS ON ANTICOCCIDIAL RESISTANCE

The review identified few studies directly evaluating anticoccidial resistance in Brazil, an increasingly urgent issue in global poultry production. Countries like India and China have already documented significant resistance due to intensive drug use, as reported by Kumar et al. (2015) and Lan et al. (2017). The lack of comparable data in Brazil limits the ability to anticipate and manage the impacts of resistance.

These limitations suggest the need for more comprehensive and collaborative studies to improve the understanding of coccidiosis epidemiology in Brazil. Standardizing diagnostic methods, expanding geographic representation, and adopting longitudinal designs can help fill these gaps. Furthermore, greater integration between studies on domestic and wild birds and systematic analysis of anticoccidial resistance are fundamental steps toward enhancing control strategies and mitigating the economic and health impacts of coccidiosis.

FUTURE RESEARCH SUGGESTIONS

Based on the identified gaps, the following research directions are recommended to advance the understanding and management of coccidiosis:

1. Conducting Longitudinal Studies

   Longitudinal investigations are essential to monitor the seasonal dynamics and persistence of *Eimeria spp.* Infections across different farming systems and regions in Brazil. These studies could correlate climatic and management factors with fluctuations in *Eimeria spp.* Prevalence, as observed in research conducted in Australia (Godwin & Morgan, 2015) and Western Europe (Györke et al., 2013). Such analyses would help identify high-risk periods and adapt control strategies more effectively.

2. Expanding Geographic Coverage

   Broadening studies to include data from northern and central-western Brazil, where information on Eimeria spp is crucial. Prevalence is scarce. Research in these areas could reveal significant regional variations influenced by specific environmental factors, such as the Amazon's high humidity and population density. Data from other tropical regions, such as Sub-Saharan Africa (Nana-Mariam et al., 2023), suggest that these environmental conditions could critically affect oocyst dissemination.

3. Investigating Alternative Farming Systems
   Most current research focuses on intensive farming systems, but there is a growing need for studies on *Eimeria spp.* in alternative systems, such as free-range and organic farming. These systems present unique challenges, including greater environmental exposure and contact with wild birds, which may increase the risk of mixed infections. Studies exploring adapted management practices, as observed in organic production in Germany (Blake & Tomley, 2014), could provide valuable guidelines for similar systems in Brazil.
4. Exploring Interactions Between Domestic and Wild Birds
   More detailed studies are needed to investigate interactions between domestic and wild birds, particularly in areas where these groups coexist, such as regions near-natural habitats and farms. This line of research is essential to understanding the cross-transmission of Eimeria spp. The work by Snak et al. (2014), which evaluated *Eimeria* prevalence in captive birds in Brazil, suggests that wild birds may act as essential reservoirs. Still, there is limited data on the impact of these interactions on commercial farms.
5. Evaluating New Control Strategies
   Anticoccidial resistance is a growing concern in global poultry farming, highlighting the need for research assessing the efficacy of new vaccines, probiotics, and feed additives. Recent studies in China and India (Lan et al., 2017; Kumar et al., 2015) have shown promising results with multivalent vaccines and natural feed additives. Additionally, considering Brazil's heterogeneity of farming systems, investigating the economic feasibility and practical implementation of these strategies is essential. Clinical trials and field studies could help determine the most effective combinations of control measures in different regions and management contexts.
6. Integrating Advanced Technologies
   Emerging technologies, such as artificial intelligence and big data analytics, can be incorporated to predict *Eimeria spp—Outbreaks* based on environmental and management factors. Countries like the United States already use automated systems to monitor production and animal health data, optimizing disease control interventions (Blake & Tomley, 2014). Adapting these technologies to Brazil could represent a significant advancement in coccidiosis management.

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These future research directions aim to fill critical knowledge gaps in *Eimeria spp.* Epidemiology while developing strategies tailored to diverse regional realities. By combining longitudinal studies, expanded geographic coverage, and evaluations of new technologies and control strategies, Brazil could advance the implementation of more effective and sustainable coccidiosis management measures. Additionally, lessons learned in the Brazilian context could be applied to other countries facing similar challenges, contributing to a more integrated global approach.

CONCLUSION

The high prevalence of *Eimeria spp.*, including mixed infections, underscores the need for strategies based on accurate diagnostics and sustainable practices. Anticoccidial resistance and environmental challenges make adopting solutions such as vaccines, probiotics, and alternative management strategies urgent, as they can potentially mitigate coccidiosis. However, the lack of studies in underexplored regions and continuous monitoring limit progress in disease control. Investing in geographically representative research and integrated technologies is fundamental for fostering a more resilient and sustainable poultry industry.

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