Alrammahi *et. al.,* Babcock Univ. Med. J.2025 8(2):145-155
https://doi.org/10.38029/babcockuniv.med.j..v8i2.978
eISSN: 2756-4657

RESEARCH ARTICLE OPEN ACCESS

Comparative pathophysiological impact of *Eimeria* spp. infection in four avian species: A biochemical, haematological, and histological study

Alrammahi IY[1], Mahood HE[1ID], Alshaebani KT[1ID]

[1]*Department of Biology, College of Education, University of Al-Qadisiyah, Iraq*

Submitted: 8th February 2025
Accepted: 13th June 2025
Published: 31st December 2025
ID: Orcid ID

Abstract
Background: Intestinal coccidiosis caused by *Eimeria* spp. represents a major parasitic disease affecting poultry and other avian species, leading to significant economic and health impacts. This study aimed to assess the biochemical, immunological, haematological, and histopathological alterations associated with *Eimeria* infection in four bird species: chicken, chicken rose, duck, and pigeon.
Methods: A total of 191 intestinal samples were microscopically examined, and biochemical parameters (AST, ALT, MDA, GSH), cytokine levels (IL-10), and blood indices (RBC, WBC) were measured. Histological sections from the duodenum, cecum, and mid-intestine were analysed using H&E staining to evaluate tissue damage.
Results: Overall infection prevalence reached 62.3%, with no significant difference among species (P = 0.577). Infected birds showed markedly elevated oxidative stress markers (AST, ALT, MDA), increased IL-10 levels, and significant haematological shifts, including leucocytosis and anaemia. Histologically, infected tissues exhibited severe pathological lesions such as villous atrophy, epithelial sloughing, inflammatory infiltration, and presence of parasitic cysts, with variable severity among species.
Conclusion: *Eimeria* spp. infection induces systemic and local alterations in affected birds, reflected in biochemical imbalance, immune activation, and histopathological damage. These findings underscore the importance of integrated diagnostic approaches combining molecular, serological, and histological methods to improve detection, prevention, and control of coccidiosis in avian hosts.

Keywords: *Eimeria spp.*, Coccidiosis, Avian species, Histopathology, Oxidative stress, IL-10, AST, Haematological parameters, ALT, Intestinal lesions

Plain English Summary

A common parasite named *Eimeria* causes a disease called coccidiosis in poultry birds. This study looked at how this parasite affects four different types of birds: chickens, chicken rose, ducks, and pigeons. The researchers tested 191 bird samples for infection and found that about 62% were infected, regardless of the bird species. In infected birds, there were signs of stress and damage in their bodies, supported by higher levels of certain liver enzymes (AST and ALT) and stress markers (MDA). There were also notable changes in the blood, such as increased white blood cells (suggesting infection) and reduced red blood cells (suggesting anaemia). An increase in an immune system protein called IL-10 was also observed.

Correspondence:
Alrammahi Intisar Y
Department of Biology, College of Education
University of Al-Qadisiyah
Iraq
+9647723817225, edu.bio.posta7@qu.edu.iq

Observing the bird's intestinal cells under a microscope revealed damaged, shortened finger-like projections (villi), loss of the top layer of cells, inflammation, and the presence of parasites in the tissues. In summary, the study showed that *Eimeria* infections can cause serious health problems for birds, affecting their bodies in different ways. It highlights the need for using different methods (like blood tests, tissue analysis, and parasite detection) to better diagnose and manage this disease in birds.

Introduction

Avian coccidiosis, caused by protozoa of the genus *Eimeria*, remains one of the most economically devastating and globally prevalent parasitic diseases in poultry production systems. These obligate intracellular parasites infect specific regions of the intestinal epithelium, resulting in tissue destruction, malabsorption, impaired growth, and, in severe cases, high mortality rates among infected birds. The global poultry industry incurs economic losses worth billions of dollars annually due to coccidiosis. This is primarily due to reduced productivity, the cost of prophylaxis, and treatment strategies (1, 2). Among poultry, chickens have been the primary focus of coccidiosis research, however, recent studies highlight the importance of recognizing other susceptible avian species such as ducks, pigeons, and coloured broilers (e.g., chicken rose) in the epidemiology of the disease, especially under backyard or semi-intensive management systems where exposure to sporulated oocysts is higher and immune prophylaxis is inconsistent (3, 4). Chicken rose (Gallus gallus domesticus) is a local commercial hybrid broiler type distinguished by its reddish plumage and commonly raised in backyard settings. In such systems, the spread of *Eimeria* spp. is facilitated by environmental contamination and interspecific cohabitation, allowing for variation in infection outcomes among species. Although not a formally recognised breed, it is widely used in semi-intensive poultry production across the region.

Upon ingestion, *Eimeria* oocysts excyst in the intestinal tract and initiate cycles of schizogony and gametogony within enterocytes, causing a cascade of pathological changes. These include villous atrophy, epithelial necrosis, intestinal gland hyperplasia, and severe inflammatory infiltration—lesions that compromise digestive efficiency and systemic homeostasis (5, 6). Concurrently, the infection elicits complex host immune responses involving innate and adaptive components. Cytokines such as interferon-gamma (IFN-γ), interleukin-10 (IL-10), and tumour necrosis factor-alpha (TNF-α) are upregulated, orchestrating both parasite clearance and inflammatory pathology (7, 8, 9). While extensive research has focused on Eimeria infections in chickens, particularly in commercial broiler and layer operations, comparative studies involving other avian hosts remain scarce. Backyard and mixed-species flocks, which are common in many regions, often include ducks, pigeons, and coloured broiler varieties such as 'chicken rose'. These species differ in gut physiology, immune response, and exposure to infection, potentially influencing the severity and manifestation of coccidiosis. However, the lack of systematic comparative data on Eimeria-induced pathology across different avian species represents a significant knowledge gap. This study addresses that gap by providing a cross-species assessment of haematological, biochemical, immunological, and histological changes associated with natural Eimeria infections.

Biochemically, *Eimeria*-induced damage leads to hepatic stress and oxidative imbalance, as indicated by elevated levels of liver enzymes (AST, ALT), malondialdehyde (MDA), and alterations in antioxidant biomarkers such as glutathione (GSH) (10). Haematologically, infected birds often exhibit anaemia, either haemorrhagic or haemolytic, alongside leucocytosis and shifts in immune cell populations, reflecting systemic inflammation and immune activation (11, 12).

Histopathological evaluation is a cornerstone in the diagnosis and understanding of coccidial infection severity. Distinct *Eimeria* species preferentially colonise specific intestinal segments; for example, *E. tenella* predominantly targets the cecum, while *E. acervulina* affects the duodenum (13). Differences in tissue damage patterns can be observed between species, reflecting host susceptibility, immune competence, and parasite strain virulence.

Although individual studies have addressed the pathogenesis of *Eimeria* in single avian species, limited comparative data are available evaluating the systemic and local responses across different hosts under natural or semi-natural infection scenarios. Such comparative insights are essential for developing species-specific prevention and control strategies, especially in mixed-flock settings.

Therefore, the present study aims to provide a comprehensive evaluation of the haematological, immunological, biochemical, and histopathological alterations induced by *Eimeria* spp. in four different avian species: chicken, chicken rose, duck, and

pigeon. Through a multidisciplinary approach encompassing blood profile analysis, cytokine quantification, oxidative stress assessment, and detailed intestinal histopathology, this research seeks to highlight both shared and species-specific patterns of host response, with implications for targeted disease control in diverse poultry systems.

Materials and Methods

Study Design and Sample Collection

This comparative study involved four avian species: chicken (*Gallus gallus domesticus*), chicken rose, duck (*Anas platyrhynchos*), and pigeon (*Columba livia*). A total of 191 birds were examined, and both infected and non-infected individuals were identified based on microscopic detection of *Eimeria spp.* in intestinal contents. Blood and tissue samples were collected postmortem under sterile conditions.

The number of birds sampled per species varied due to differences in flock availability during the sampling period, particularly in semi-intensive and backyard poultry systems. These settings naturally presented variable species compositions, with a higher number of chicken rose birds available compared to pigeons and ducks. Although statistical analyses were applied to adjust for this variation, we acknowledge that uneven group sizes may influence the comparative precision of certain results and have discussed this as a limitation.

This study was conducted under field conditions without experimental infection. Birds were naturally exposed to Eimeria spp. in their respective management environments. Non-infected birds were identified based on the absence of oocysts following two successive microscopic examinations of intestinal contents at different time points. While PCR or molecular confirmation was not performed due to resource limitations, birds included in the non-infected group showed no clinical signs and tested negative microscopically, reducing the likelihood of subclinical infection

Histological Procedures

Tissue samples from the intestine, cecum, liver, and spleen were fixed in 10% neutral buffered formalin for 24–28 hours. The samples were washed with running water for 3 hours and dehydrated through graded ethanol concentrations (70%, 80%, 90%, 95%, and 100%). Clearing was performed using xylene, followed by paraffin embedding. Sections were cut at 5 µm thickness using a rotary microtome. The slides were stained with haematoxylin and eosin following standard protocols (13). The stained sections were mounted using DPX and examined under a light microscope for histopathological evaluation.

Haematological Analysis

Complete blood count (CBC) was conducted to determine red blood cell (RBC) and white blood cell (WBC) counts using an automated haematology analyser. Blood samples were collected in EDTA tubes and analysed within two hours of collection to ensure data accuracy.

Immunological Assessment

The levels of the anti-inflammatory cytokine IL-10 were measured in serum samples using a commercial ELISA kit (Elabscience®, USA) according to the manufacturer's instructions. Measurements were performed in duplicate, and the absorbance was read at 450 nm using a microplate reader.

Biochemical Analysis

Serum samples were analysed for oxidative stress markers, including alanine aminotransferase (ALT), aspartate aminotransferase (AST), malondialdehyde (MDA), and glutathione (GSH). ALT and AST were assessed using commercially available kits (Biolabo®, France) based on kinetic UV methods. Readings were taken at 340 nm, and enzyme activity was expressed in IU/L. MDA levels were determined spectrophotometrically using a thiobarbituric acid-reactive substances (TBARS) assay kit. Tissue or serum samples were mixed with extraction reagent, followed by MDA working solution, and incubated at 100°C for 60 minutes. Absorbance was measured at 532 nm and 600 nm, and MDA concentration was calculated accordingly. GSH concentrations were measured using a colourimetric assay (MyBioSource®) where DTNB reacts with GSH to form a yellow compound, read at 412 nm. Samples were prepared by homogenising tissue in metaphosphoric acid and centrifuging at 10,000 × g for 15 minutes at 4°C.

Statistical Analysis

Data were analysed using SPSS software version XX (IBM Corp., Armonk, NY). Differences in prevalence between groups were assessed using the Chi-square (χ^2) test. For biochemical, haematological, and immunological data, one-way analysis of variance (ANOVA) was used, followed by Least Significant Difference (LSD) post-hoc testing to identify significant pairwise differences. A p-value < 0.05 was considered statistically significant. All results are presented as mean ± standard error (SE)

Results

The histopathological assessment demonstrated notable variations between the intestinal tissues of non-infected and Eimeria spp.-infected birds, as summarised in Table 1 and illustrated across Figures 1 to 4. Each figure comprises four images representing the four studied bird species in the following order: (1) Chicken, (2) Chicken rose, (3) Duck, and (4) Pigeon. Within each image, specific histological structures or pathological features are labelled with the letters A, B, C, and, where applicable, D, to clarify the observed changes.

Table 1. Comparative Histopathological Findings in Birds Infected with Eimeria spp.

Site	Chicken	Chicken Rose	Duck	Pigeon
Intestine (non-infected)	Normal finger-like villi, intestinal glands, and smooth muscle layer	Intact finger-like villi, simple columnar epithelium, and goblet cells	Finger-like villi with simple columnar epithelium and microvilli	Normal villi, intestinal glands, and smooth muscle layer
Duodenum (Infected)	Destruction of villus epithelial cells and severe villous atrophy	Villus destruction, necrosis, and presence of parasitic cyst-like structures	Contraction of intestinal glands, inflammatory cell infiltration, and parasite proliferation within villi	Villus sloughing and destruction, infiltration of lymphocytes and other inflammatory cells, and parasitic cysts
Cecum (Infected)	Villus destruction, inflammatory cell infiltration, smooth muscle layer detachment, and presence of parasitic cysts	Atrophy of intestinal glands, mucosal layer sloughing, and villus tip destruction	Villus atrophy, mucosal detachment, and presence of parasitic cystic structures	Atrophy of intestinal glands, mucosal layer sloughing, and parasitic cyst structures
Mid Intestine (Infected)	Villus damage and sloughing, atrophy, and infiltration of inflammatory cells	Atrophy of villi and glands, and sloughing of smooth muscle layers	Destruction of villi in the duodenum, epithelial detachment, and infiltration of lymphoid and other inflammatory cells	Villus destruction and sloughing, parasitic cystic structures, and inflammatory cell infiltration

Normal Intestine- Non-infected Tissue

Figure 1 presents the histological architecture of the normal (non-infected) intestine. In all four bird species, the tissues appeared healthy and intact. Chicken intestine (1) revealed well-developed finger-like villi (A), organised intestinal glands (B), and a continuous smooth muscle layer (C). Chicken rose (2) displayed similar finger-like villi (A), lined by simple columnar epithelium (B), with visible goblet cells. In duck (3), the finger-like villi (A) were arranged and supported by well-defined microvilli (B). The pigeon intestine (4) also showed normal structure, including preserved villi (A), well-differentiated intestinal glands (B), and smooth muscle components (C). These findings indicate a typical histological baseline for comparison.

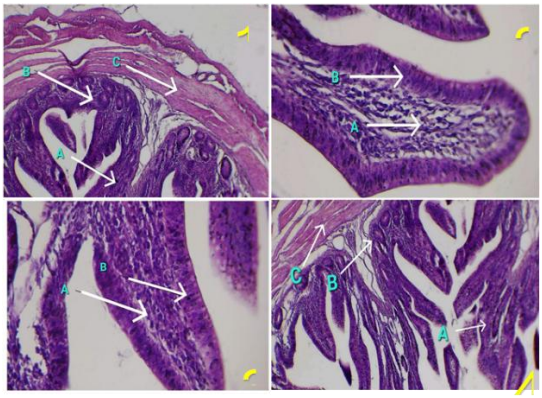

Figure 1: Normal histological architecture of the intestine in non-infected birds, microscopic sections show the normal structure of the intestine in (1) Chicken, (2) Chicken rose, (3) Duck, and (4) Pigeon, highlighting intact villi (A), intestinal glands (B), and smooth muscle layers (C). These represent the control (non-infected) group

Duodenum- Infected Tissue

The pathological alterations in the duodenum caused by Eimeria spp. are depicted in Figure 2. In chicken (1), there was pronounced destruction of the epithelial lining of the villi (A), along with severe villous atrophy (B). Chicken rose (2) displayed even more extensive damage, with complete villous collapse (A), areas of necrosis (B), and the presence of parasitic cyst-like structures embedded within the tissue (C). Duck (3) exhibited contraction of the intestinal glands (A), infiltration of inflammatory cells (B), and active parasite multiplication within the villi (C), indicating a highly active infectious process. Similarly, the pigeon duodenum (4) was characterised by villous sloughing and destruction (A), dense infiltration with lymphocytes and other inflammatory cells (B), and clear parasitic cyst formation (C).

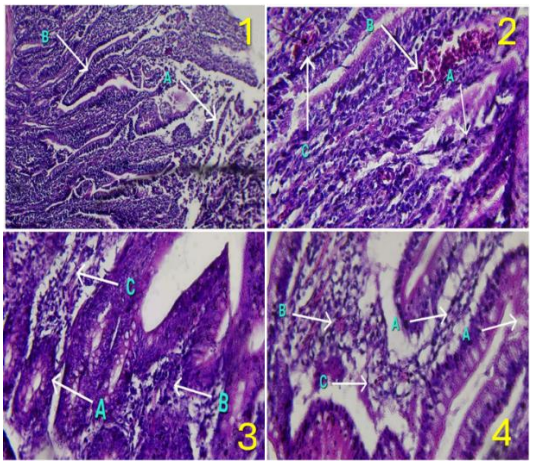

Figure 2: Histopathological changes in the duodenum of birds infected with Eimeria spp. Sections illustrate the duodenal damage in (1) Chicken, (2) Chicken rose, (3) Duck, and (4) Pigeon. Observed lesions include epithelial destruction (A), villous necrosis or atrophy (B), and parasitic cysts (C)

Caecum- Infected Tissue

Figure 3 shows the extent of pathological damage in the caecal region. In chicken (1), there was extensive villous destruction (A), accompanied by leukocytic infiltration (B), detachment of the smooth muscle layers (C), and the presence of parasitic cysts (D), marking a severe inflammatory reaction. Chicken rose (2) demonstrated marked atrophy of intestinal glands (A), complete mucosal sloughing (B), and breakdown of villous tips due to parasitic development (C). Duck (3) showed atrophic villi (A), mucosal detachment (B), and cystic parasitic structures infiltrating the tissue (C). The pigeon (4) presented with similar alterations, including glandular atrophy (A), detachment of the mucosal surface (B), and parasitic cyst inclusions (C), further confirming the susceptibility of the cecum to Eimeria spp. invasion.

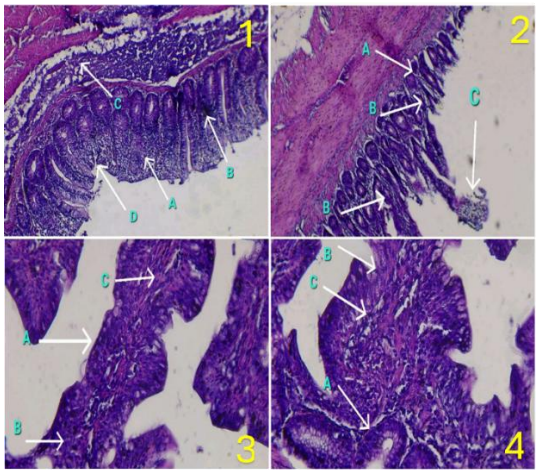

Figure 3: Caecal tissue alterations in birds infected with Eimeria spp. Histological sections from the cecum infiltration (B), mucosal detachment (C), and parasitic cyst structures (D or C, depending on species)

Mid Intestine- Infected Tissue

In Figure 4, the mid-intestinal regions of all infected birds exhibited severe degenerative changes. The chicken sample (1) showed complete sloughing and fragmentation of the villi (A), with thin, thread-like remnants (B) and intense leukocytic infiltration (C). Chicken rose (2) had significant atrophy of both villi (A) and intestinal glands (B), along with sloughing of the smooth muscle layers (C), suggesting deep tissue penetration by the parasite. The duck (3) displayed similar pathology, including destruction of villous architecture (A), epithelial detachment (B), and inflammatory infiltration rich in lymphocytes and other immune cells (C). In the pigeon (4), villous structures were heavily damaged (A), parasitic cysts were apparent (B), and there was extensive infiltration of inflammatory cells (C), indicating a robust host immune response.

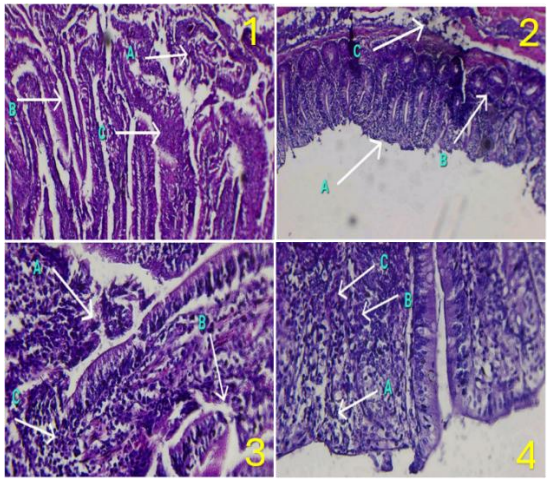

Figure 4: Pathological lesions in the mid-intestine of Eimeria-infected birds' images of the mid-intestine from (1) Chicken, (2) Chicken rose, (3) Duck, and (4) Pigeon reveal sloughing of villi (A), atrophy of mucosal or glandular layers (B), and intense leukocytic infiltration (C)

Biochemical, Immunological, and Haematological Results

Microscopic examination revealed that out of 191 total avian samples, 119 were positive for Eimeria spp., resulting in an overall infection rate of 62.30%. Infection prevalence varied across bird species, ranging from 56.09% in ducks to 72.5% in pigeons, but statistical analysis ($\chi^2 = 1.97$, $P = 0.577$) indicated no significant difference in infection rates among the groups (Table 2).

Table 2. Prevalence of Eimeria spp. in Different Avian Species Based on Microscopic Examination

Bird Species	Total Samples	Positive Samples	Percentage (%)
Chicken	41	25	60.97
Chicken rose	69	42	60.86
Duck	41	23	56.09
Pigeon	40	29	72.5
Total	191	119	62.30
X^2		1.97	
p-value		0.577*	

Biochemical oxidative stress markers showed marked differences between infected and non-infected birds (Table 3). Infected birds demonstrated significant elevations in liver enzymes (AST and ALT), malondialdehyde (MDA), and glutathione (GSH) levels compared to their non-infected counterparts. For instance, chicken rose exhibited a dramatic increase in AST (106 ± 0.06) versus (0.27 ± 0.05), and MDA (0.887 ± 0.03) compared to (0.170 ± 0.04), highlighting oxidative damage and hepatic stress induced by infection.

Table 3. Oxidative Stress Biomarkers in Infected and Non-infected Birds (Mean ± SE)

Bird Species	AST		ALT		MDA		GSH	
	Infected	Non-infected	Infected	Non-infected	Infected	Non-infected	Infected	Non-infected
chicken	1.19±0.11	0.175±0.06	1.23±0.07	0.258±0.09	0.837±0.03	0.161±0.06	0.841±0.04	0.290±0.11
chicken rose	106±0.06	0.27±0.05	0.507±0.02	0.126±0.02	0.887±0.03	0.170±0.04	0.891±0.03	0.105±0.02
Duck	1.07±0.07	0.057±0.02	0.679±0.11	0.073±0.02	0.502±0.06	0.115±0.04	0.618±0.05	0.110±0.04
Pigeon	1.04±0.08	0.368±0.09	0.800±0.06	0.302±0.09	1.005±0.04	0.495±0.13	0.830±0.02	0.152±0.04
LSD	0.251		0.187		0.178		0.117	

Note: AST and ALT values are expressed in IU/L, MDA in nmol/mL, and GSH in µmol/mL. All measurements were performed using standardised commercial assay kits

Similarly, IL-10 levels were detected exclusively in infected birds across all species, while no expression was observed in non-infected controls (Table 4). This suggests an active anti-inflammatory cytokine response triggered by the parasitic invasion.

Table 4: Serum IL-10 Levels in Infected and Non-infected Avian Species (Mean ± SE)

Bird Species	IL-10	
	Infected	Non-infected
chicken	0.535±0.01	0±0
chicken rose	0.515±0.008	0±0
duck	0.562±0.02	0±0
pigeon	0.558±0.02	0±0
LSD	0.028	

Note: AST and ALT values are expressed in IU/L, MDA in nmol/mL, and GSH in µmol/mL. All measurements were performed using standardised commercial assay kits

Haematological analysis (Table 5) revealed a substantial decrease in red blood cell (RBC) counts in infected birds, particularly in ducks and chickens, indicating possible anaemia or suppressed erythropoiesis. Conversely, white blood cell (WBC) counts were markedly elevated in infected specimens of all birds, reflecting a systemic inflammatory response. For instance, ducks showed an increase in WBCs from 0.614 ± 0.30 in non-infected birds to 4.48 ± 0.40 in infected ones.

Table 5: Haematological Indices in Infected and Non-infected Birds (Mean ± SE)

Bird Species	RBC Counts		WBC Counts	
	Infected	Non-infected	Infected	Non-infected
chicken	86.28±3.59	11.45±0.68	1.98±0.14	0.664±0.07
chicken rose	95.36±5.95	6.12±0.12	2.03±0.28	0.85±0.04
duck	42±3.14	4.68±0.27	4.48±0.40	0.614±0.30
pigeon	48.46±4.23	6.28±0.31	4.24±0.27	4.84±0.32
LSD	11.53		0.820	

Discussion

The histopathological and systemic consequences of *Eimeria* spp. infection in avian species revealed profound tissue and functional alterations, with interspecies differences that mirror variations in immune competence, parasite-host adaptation, and environmental exposure.

Histopathological Changes

Infection with *Eimeria* spp. caused notable histopathological disruptions in the intestinal tissues of all bird species studied. The most severe lesions were localised in the duodenum and cecum. These included villous atrophy, mucosal erosion, necrosis, sloughing of the epithelial lining, and the presence of intracellular parasitic cysts. These findings are consistent with those reported by Rashid and Shnawa (14), who observed severe mucosal degeneration and intestinal gland hyperplasia in chickens naturally infected with *Eimeria* spp. Similar intestinal architectural distortions have been attributed to invasive stages of *E. tenella*, which damage the lamina propria and cause extensive leukocytic infiltration (15).

Al-dujaily et al. (16) described comparable epithelial damage, glandular distortion, and haemorrhagic lesions in lambs, suggesting that similar host-parasite dynamics and inflammatory

pathways may occur across species. Weng et al. (17) emphasised the role of *Eimeria* in disrupting gut homeostasis and provoking epithelial apoptosis, especially in genetically susceptible hosts. Moreover, Saleem et al. (18) demonstrated that birds under oxidative and parasitic stress exhibit reduced mucosal thickness and immune cell infiltration, consistent with our observations.

Oxidative Stress and Liver Enzyme Alterations

The observed elevations in serum AST, ALT, malondialdehyde (MDA), and glutathione (GSH) among infected birds indicate a systemic response to oxidative stress and hepatocellular injury caused by *Eimeria* infection.

MDA, a biomarker of lipid peroxidation, was markedly increased in all infected avian species. These findings agree with Abd El Monsef et al. (19), who recorded significant MDA elevation in broiler chickens infected with *E. tenella*. The rise in GSH may represent a compensatory mechanism that aims to neutralise reactive oxygen species. Saleem et al. (18) also observed antioxidant responses to parasitic stress. El-Hack et al. (20) reported similar elevations in liver enzymes and oxidative markers in infected chickens. Alkhudhayri et al. (21) observed mitochondrial dysfunction and increased peroxidative load due to coccidial invasion. Zhou et al. (22) found that ducks exhibited relatively lower oxidative stress markers compared to chickens.

Haematological Alterations (RBC and WBC)

The haematological evaluation revealed reduced RBC counts and elevated WBC levels in infected birds. Kadim et al. (23) noted a marked reduction in erythrocyte counts in broiler chickens with severe coccidial infections. Al-dujaily et al. (16) described anaemia of inflammatory origin in infected lambs. The substantial leucocytosis observed indicates a strong innate immune response, like findings by Calik et al. (24), who reported elevated leukocyte counts in broilers during peak infection. Weng et al. (17) highlighted that *Eimeria* induces recruitment of neutrophils and mononuclear phagocytes into the intestinal mucosa. Abbas et al. (25) noted that the severity of haematological changes varies with the infecting species and host genetics.

Immune Response and IL-10 Modulation

IL-10 was exclusively detected in all infected birds, while absent in non-infected controls. Weng et al. (17) noted that *Eimeria* induces IL-10 expression in the intestinal mucosa to suppress IFN-γ and TNF-α secretion. Zhou et al. (22) demonstrated species-specific variability in cytokine expression. Gao et al. (26) linked IL-10 upregulation with genetic polymorphisms in cytokine promoter regions. El-Hack et al. (20) emphasised the role of immunomodulators in enhancing IL-10. Rashid and Shnawa (14) observed IL-10 elevation in natural coccidiosis cases, coinciding with lesion development.

Species-Specific Responses to Eimeria Infection

Although infection prevalence was similar across species, pathological and immunological responses varied. The chicken rose group exhibited more extensive duodenal lesions, possibly indicating higher susceptibility. Abbas et al. (25) reported that commercial poultry lines are often more vulnerable to *Eimeria* than indigenous breeds. Ducks showed milder histological damage, consistent with Zhou et al. (22). Pigeons exhibited high leukocytic infiltration and IL-10 levels, suggesting delayed immune activation. Gao et al. (26) linked interspecies variability in cytokine gene expression to different immune outcomes. Ali et al. (27) demonstrated differences in baseline antioxidant capacities between species. El-Shall et al. (28) concluded that host genetic background modulates susceptibility and lesion severity in coccidiosis. Although the infection prevalence did not differ significantly among species ($P = 0.577$), the pathological, biochemical, and immunological responses varied markedly. This suggests that while exposure to Eimeria spp. may be similar across species in shared environments, host-specific factors determine the severity and nature of disease expression. Therefore, the interspecies variability lies not in infection rates but in the physiological and immune consequences of infection.

The relatively milder histological damage observed in ducks may be attributed to species-specific differences in gut morphology, microbiota composition, and immune regulation. Ducks possess longer intestinal transit times and thicker mucosal layers, which may offer partial protection against intracellular parasites like Eimeria spp. Additionally, waterfowl are known to exhibit a more controlled inflammatory response, possibly reducing tissue destruction during infection. Zhou et al. (22) reported less pronounced barrier damage and lower oxidative stress markers in ducks compared to chickens, supporting this interpretation. These anatomical and immunological distinctions may contribute to differential susceptibility despite similar infection rates.

Study limitations
A key limitation of this study is that only the anti-inflammatory cytokine IL-10 was measured. While its elevation in infected birds suggests immunomodulatory activity, the absence of data on pro-inflammatory cytokines such as IFN-γ and TNF-α limits our ability to fully interpret the balance between immune activation and regulation during Eimeria infection. Future studies incorporating broader cytokine panels are essential to delineate the dynamic interplay of immune responses and better understand host-pathogen interactions across avian species. Also, it is important to acknowledge that the uneven group sizes across bird species, which were determined by availability during field sampling, may influence the comparative precision of certain results. While statistical adjustments were applied, such disparities could affect the robustness of interspecies comparisons, particularly in parameters with subtle differences. Future studies with balanced sample sizes are recommended to enhance statistical power and comparability

Conclusion
The study demonstrated that *Eimeria spp.* infection induces significant pathological alterations across four avian species, with varying severity. While infection prevalence appeared uniform across species, the differential host responses underscore the need for species-tailored diagnostic and management strategies. Histopathological changes included villous atrophy, epithelial disruption, and inflammatory infiltration, especially in the cecum and mid-intestine. Biochemical analysis revealed elevated AST, ALT, MDA, and GSH levels in infected birds, indicating oxidative stress and liver involvement. Haematologically, a decrease in RBCs and an increase in WBCs suggested anaemia and systemic inflammation. The exclusive presence of IL-10 in infected birds further confirmed an active immune response. These findings highlight the serious impact of *Eimeria spp.* on avian health and stress the need for early diagnosis and effective control measures.

List of Abbreviations
ALT: Alanine Aminotransferase
AST: Aspartate Aminotransferase
CBC: Complete Blood Count
DPX: Distrene Plasticiser Xylene (mounting medium)
EDTA: Ethylenediaminetetraacetic Acid
ELISA: Enzyme-Linked Immunosorbent Assay
GSH: Glutathione
H&E: Haematoxylin and Eosin
IFN-γ: Interferon-gamma
IL-10: Interleukin-10
IU/L: International Units per Litre
LSD: Least Significant Difference
MDA: Malondialdehyde
RBC: Red Blood Cell
SE: Standard Error
TBARS: Thiobarbituric Acid Reactive Substances
TNF-α: Tumour Necrosis Factor-alpha
UV: Ultraviolet
WBC: White Blood Cell

Declarations
Ethics approval and consent to participate
This study was approved by the Animal Ethics Committee of the College of Education, University of Al-Qadisiyah, Iraq (Approval No. EDU/ETHICS/2024/017, dated 15 December 2024). All procedures were carried out following international guidelines for the care and use of animals in scientific research.

Consent for Publication
All the authors gave consent for the publication of the work under the Creative Commons Attribution Non-Commercial 4.0 license.

Availability of Data
Data for this work is available from the authors and may be provided upon reasonable request.

Conflicts of Interest
None.

Funding
None.

Authors' contributions
AIY: Conducted the experimental work, collected and analysed the data, and drafted the initial version of the manuscript. MHE: Participated in laboratory procedures, assisted in data analysis, and contributed to the preparation of figures and tables. AKT: Provided academic supervision, guided the research design and interpretation of results, and revised the manuscript critically for intellectual content.

Acknowledgments
We would like to express our thanks to the Department of Biology, College of Education for Girls, University of Al-Qadisiyah, for creating an appropriate academic environment for conducting this work and making available the required facilities. We thank the faculty and laboratory staff

for their support, assistance, and encouragement during the study.

References

1. Bremner A, Kim S, Morris KM, Nolan MJ, Borowska D, Wu Z, Tomley F, Blake DP, Hawken R, Kaiser P, Vervelde L. Kinetics of the cellular and transcriptomic response to Eimeria maxima in relatively resistant and susceptible chicken lines. Frontiers in Immunology. 2021 Mar 25;12:653085. https://doi.org/10.3389/fimmu.2021.653085
2. Chen C, Chen Y, Lu M, Xu L, Yan R, Li X, Song X. IFN-γ inhibitory molecules derived from Eimeria maxima inhibit IL-12 secretion by modulating MAPK pathways in chicken macrophages. Poultry Science. 2024 Feb 1;103(2):103359. https://doi.org/10.1016/j.psj.2023.103359
3. Jawad TI, Jasim GA. Molecular detection and histopathological changes caused by Eimeria tenella in broilers in Al-Diwaniyah Province, Iraq. Open Veterinary Journal. 2025 Feb 28;15(2):714. https://doi.org/10.5455/OVJ.2025.v15.i2.20
4. Fries-Craft K, Lamont SJ, Bobeck EA. Implementing real-time immunometabolic assays and immune cell profiling to evaluate systemic immune response variations to Eimeria challenge in three novel layer genetic lines. Frontiers in Veterinary Science. 2023 Apr 18;10:1179198. https://doi.org/10.3389/fvets.2023.1179198
5. Bafundo KW, McCullough KN. Endogenous Development and Histopathological Differences Among the Chicken Eimeria: A Review. Avian Diseases. 2025 Mar 1;69(1):6-15. https://doi.org/10.1637/aviandiseases-D-24-00075
6. Al-dujaily AH, Al-mialy AJ. Clinical and hemato-biochemical studies in Awassi lambs infected with coccidiosis. Kufa Journal for Veterinary Medical Sciences. 2017;8(1). https://doi.org/10.36326/kjvs/2017/v8i14322
7. Adamu M, Boonkaewwan C, Gongruttananun N, Vongpakorn M. Hematological, biochemical and histopathological changes caused by coccidiosis in chickens. Agriculture and Natural Resources. 2013 Apr 30;47(2):238-46.
8. Weng S, Tian E, Gao M, Zhang S, Yang G, Zhou B. Eimeria: Navigating complex intestinal ecosystems. Plos Pathogens. 2024 Nov 22;20(11):e1012689. https://doi.org/10.1371/journal.ppat.1012689
9. Calik A, Omara II, White MB, Li W, Dalloul RA. Effects of dietary direct fed microbial supplementation on performance, intestinal morphology and immune response of broiler chickens challenged with coccidiosis. Frontiers in veterinary science. 2019 Dec 12;6:463. https://doi.org/10.3389/fvets.2019.00463
10. Abd El Monsef AG, El Zohairy NF, Hassan MF, Salem SM, Gouda AA, Mansour MK, Alkhaldi AA, Alzaylaee H, Elmahallawy EK. Effects of prebiotic (lactoferrin) and diclazuril on broiler chickens experimentally infected with Eimeria tenella. Frontiers in Veterinary Science. 2024 Jul 5;11:1416459. https://doi.org/10.3389/fvets.2024.1416459
11. Soroushianfar M, Sadr S, Sazmand A, Dianaty S, Khedri J, Schuster RK, Borji H. Gastrointestinal parasites of cats in the Middle East (2000− 2023): A literature review. Parasitology International. 2024 Jul 1:102919. https://doi.org/10.1016/j.parint.2024.102919
12. Rashid SM, Shnawa BH. Prevalence, Morphometric, Genomic and Histopathological Studies in Backyard Chickens Coccidiosis in Soran City, Erbil-Iraq. Pakistan Veterinary Journal. 2024 Apr 1;44(2). http://dx.doi.org/10.29261/pakvetj/2024.187
13. El-Ghareeb WR, Kishawy AT, Anter RG, Aboelabbas Gouda A, Abdelaziz WS, Alhawas B, Meligy AM, Abdel-Raheem SM, Ismail H, Ibrahim D. 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. 2023 Apr 28;12(5):1026. https://doi.org/10.3390/antiox12051026
14. Gao Y, Sun P, Hu D, Tang X, Zhang S, Shi F, Yan X, Yan W, Shi T, Wang S, Zou J. Advancements in understanding chicken coccidiosis: From Eimeria biology to innovative control strategies. One Health Advances. 2024 Feb 27;2(1):6. https://doi.org/10.1186/s44280-024-00039-x
15. Kumar S, Garg R, Moftah A, Clark EL, Macdonald SE, Chaudhry AS, Sparagano O, Banerjee PS, Kundu K, Tomley FM, Blake DP. An optimised protocol for molecular identification of Eimeria from chickens. Veterinary Parasitology. 2014 Jan 17;199(1-2):24-31. https://doi.org/10.1016/j.vetpar.2013.09.026
16. AL-Eodawee EM, Essa IM, Al-Shaeli SJ, Al-Abedi GJ. Microscopic detection of coccidiosis in small ruminants in Wasit Province, Iraq. MINAR Int J Appl Sci Technol. 2023 Dec;4(2): https://doi.org/10.47832/2717-8234.17.8

17. Zhou BH, Jia LS, Wei SS, Ding HY, Yang JY, Wang HW. Effects of Eimeria tenella infection on the barrier damage and microbiota diversity of chicken cecum. Poultry science. 2020 Mar 1;99(3):1297-305. https://doi.org/10.1016/j.psj.2019.10.073
18. Elmahallawy EK, Fehaid A, El-Shewehy DM, Ramez AM, Alkhaldi AA, Mady R, Nasr NE, Arafat N, Hassanen EA, Alsharif KF, Abdo W. S-methylcysteine ameliorates the intestinal damage induced by Eimeria tenella infection via targeting oxidative stress and inflammatory modulators. Frontiers in Veterinary Science. 2022 Jan 5;8:754991. https://doi.org/10.3389/fvets.2021.754991
19. Alsulami MN, El-Saadony MT. Supplementing broiler diets with bacterial selenium nanoparticles enhancing performance, carcass traits, blood indices, antioxidant status, and caecal microbiota of Eimeria tenella-infected broiler chickens. Poultry Science. 2023 Dec 1;102(12):103111. https://doi.org/10.1016/j.psj.2023.103111
20. Huang CM, Lee TT. Immunomodulatory effects of phytogenics in chickens and pigs—A review. Asian-Australasian journal of animal sciences. 2017 Dec 19;31(5):617. https://doi.org/10.5713/ajas.17.0657
21. Biabani N, Taherpour K, Ghasemi HA, Akbari Gharaei M, Hafizi M, Nazaran MH. Advanced chelate technology-based trace minerals reduce inflammation and oxidative stress in Eimeria-infected broilers by modulating NF-kB and Nrf2 pathways. Scientific Reports. 2024 Oct 16;14(1):24227. https://doi.org/10.1038/s41598-024-75695-5
22. Zhou X, Wang L, Wang Z, Zhu P, Chen Y, Yu C, Chen S, Xie Y. Impacts of Eimeria coinfection on growth performance, intestinal health and immune responses of broiler chickens. Veterinary Parasitology. 2023 Oct 1;322:110019. https://doi.org/10.1016/j.vetpar.2023.110019
23. Hambesha PT, Orakpoghenor O, Abdu PA, Jatau ID, Aluwong T. Assessment of the serum biochemical changes in Eimeria tenella-challenged broiler chickens pre-treated with methanol extracts of Ganoderma lucidum, Vernonia amygdalina leaves, and Vitellaria paradoxa stem bark. Veterinary Research Notes. 2023 Nov 8;3(10):79-. https://doi.org/10.5455/vrn.2023.c32
24. Khukhodziinai JS, Das PK, Mukherjee J, Banerjee D, Ghosh PR, Das AK, Samanta I, Jas R, Mondal S, Patra AK. Effect of dietary benzoic acid and oregano essential oil as a substitute for an anti-coccidial agent on growth performance and physiological and immunological responses in broiler chickens challenged with Eimeria species. Animals. 2024 Oct 17;14(20):3008. https://doi.org/10.3390/ani14203008
25. Abbas RZ, Iqbal Z, Sindhu Z-U-D, Khan MN, Arshad M. Vaccines against chicken coccidiosis: a review of progress, challenges, and opportunities during the last decade. Parasitol Res. 2022 Oct;121(10):2749–2763. https://doi.org/10.1007/s00436-022-07585-7
26. Hong YH, Lillehoj HS, Lillehoj EP, Lee SH. Changes in immune-related gene expression and intestinal lymphocyte subpopulations following Eimeria maxima infection of chickens. Veterinary immunology and immunopathology. 2006 Dec 15;114(3-4):259-72. https://doi.org/10.1016/j.vetimm.2006.08.006
27. Faraguna S, Milinković Tur S, Sobočanec S, Pinterić M, Belić M. Assessment of Oxidative Stress and Associated Biomarkers in Wild Avian Species. Animals. 2025 Apr 23;15(9):1203. https://doi.org/10.3390/ani15091203
28. Jawad TI, Jasim GA. Molecular detection and histopathological changes caused by Eimeria tenella in broilers in Al-Diwaniyah Province, Iraq. Open Veterinary Journal. 2025 Feb 28;15(2):714. https://doi.org/10.5455/OVJ.2025.v15.i2.20