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Landmarks in Quail Coccidiosis Research with Special Scrutiny to the Available Egyptian Literature: A Review

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ABSTRACT

Quails are an important alternative to chicken production for protein sources, offering many advantages over other poultry species. However, raising quail faces certain challenges, such as a shortage of specified hatcheries and the lack of local markets for quail eggs and meat, particularly in Egypt. In addition, there is less interest in quail's medication and vaccine production. A significant disease affecting the health and productivity of quails is coccidiosis, which is associated with poor feed conversion ratio, lower growth performance, heightened mortality, and high cost of vaccination and treatment. Attention to quail coccidiosis and its clinical forms, diagnosis, morphological characterization, control, and prevention is very critical for improving quail meat and egg production. This review compiles scientific data on quail coccidiosis, with a focus on literature from Egypt, for classification, data analysis, and processing.

Keywords: Anticoccidial, Coccidiosis, *Eimeria*, Egyptian, Morphology characterization, Quail

INTRODUCTION

Coccidiosis is a protozoan disease caused by coccidia of the genus *Eimeria* (Kemp et al., 2013). Over 1800 different species of *Eimeria* invade and infect the digestive tracts of mammals and birds, either wild or domesticated (Haug et al., 2008). When *Eimeria* species target the intestinal tract, they induce a potent inflammatory response and tissue damage, with increased susceptibility to other disease agents, and mortalities in severe cases (Duszynski, 2011). *Eimeria* species have a complex life cycle that involves both intra- and extracellular stages and is completed in a single host due to their high host specificity, in particular *Eimeria (E.) tsunodai*, *E. uzura*, and *E. bateri* in quails (Lu et al., 2021). Each *Eimeria* species replicates to form oocysts in the intestine of the host, which are then released into the environment via feces. Birds ingest sporulated oocysts, which are then transported to the intestine to begin their life cycle (Chapman, 2014).

Several studies have focused on the pathogenesis, pathogenicity, control, and prevention of coccidia in domesticated poultry due to the significant economic losses associated with both subclinical and clinical infections (Nawarathne et al., 2021). Quails, in particular, are considered a viable alternative in poultry production because of their high potential for meat and egg production. Quail farming is a rapidly developing sector worldwide (Lukanov, 2019). In Egypt, with a growing population and an increasing demand for animal proteins, quail breeding has gained attention as a means to boost and expand the production of meat protein (Arafat and Abbas, 2018; Ramadan et al., 2021). Quails are susceptible to several diseases, with coccidiosis being the most significant. This dangerous parasitic disease poses a major threat to the quail industry (Umar et al., 2014). On the other hand, there is limited information available about quail coccidiosis, including its distinct phenotypic and genetic characteristics (Arafat and Abbas, 2018).

This article could provide the existing studies on coccidiosis in quails, emphasizing the disease's distinguishing characteristics and key features. The review focuses particularly on data and results from available literature, with special attention to studies conducted in Egypt.

MATERIALS AND METHODS

In the current review, the available literature of previous international and Egyptian studies (Scopus, PubMed, and Google Scholar) concerned with quail coccidiosis were carefully reviewed and studied. The related literature was classified and submitted for data breakdown and dispensation. A total of 43 studies were reviewed, including 33 international and 10 Egyptian studies. The collected data encompassed the main characteristics of quail coccidiosis, such as the types of *Eimeria*, clinical findings, gross and histopathological features, diagnostic procedures, and control approaches. The findings from these studies, particularly those from Egypt, were presented in tables and figures, and conclusions were drawn to provide recommendations for stakeholders in the quail industry.

Quails and its products

Quail is a medium-sized bird that belongs to various genera of the family *Phasianidae* (Abd El-Ghany, 2019). Quail production is a short-generation industry with the potential to meet the nutritional and economic needs of developing countries (Ojo et al., 2014). Quail breeding offers numerous advantages, including early sexual maturity, low feed consumption (20-25 g/adult bird/day), high production rate with 300 eggs/year, low mortality rate, highly nutritious meat and eggs, and short generation time (3-4 generations annually, Faitarone et al, 2005; Bashtar et al., 2010; Jatoi et al., 2013). Additionally, they are distinguished by their low startup expenses and small rearing areas (200-250 and 150-200 cm^2 in litter and cage systems, respectively), which suggests a unique trend in poultry production (Shemshadi et al., 2014; Hassan et al., 2017; Yambayamba and Chileshe, 2019).

Quail eggs are inexpensive sources of protein, particularly in developing countries. They are also rich in iron, phosphorus, riboflavin, pantothenic acid, folate, vitamin B12, and selenium (Kalsum et al., 2012). Quail's meat is a healthier choice for people who are health-conscious because it has less fat and calories while offering more moisture and minerals than broiler meat (Wahab, 2002; Tunsaringkarn et al., 2013).

Among the many quail breeds under domestication, the Japanese quail (*Coturnix japonica*) and the Bobwhite quail (*Colinus virginianus*) are the most common species reared in Egypt (Arya et al., 2018; Abd El-Ghany, 2019). Quails have been domesticated in Egypt since ancient times, alongside chickens, ducks, pigeons, and other birds. Quail was a favored food of the ancient Egyptians, as depicted on the walls of many Egyptian temples (Halim et al., 2022). Globally, the breeding of Japanese quails has flourished in aviculture due to the increasing demand for meat and eggs (Berto et al., 2011). The Japanese quail is a migratory bird that inhabits East Asia (Faizullah et al., 2021). Egypt is one of the most significant countries for migrating birds, with at least 300 different species traveling there from all over the world each year (Mazyad et al., 1999). The migratory quail, also called the common quail, travels from Europe to Egypt throughout the autumn (Benskin et al., 2009). The Egyptian northern coast, from Matrouh in the west to the Saini peninsula in the east, as well as the cities of Edko and Rashid, which are districts of the Elbehera governorate near the Mediterranean Sea, is a terminus for many migratory birds, including quails (Waheeb et al., 2022).

Etiology of quail coccidiosis

Coccidiosis is typically a hidden disease in quails that lowers production and growth rate, and increases mortality (Simiyoon et al., 2018). The coccidial infection causes an imbalance in the gut microbiota and impairs digestion and absorption, increasing the chance of contracting another bacterial infection. When more pathogenic bacteria proliferate, the functions of the intestinal mucosal barrier are compromised, and the immune system becomes less capable of recognizing and attacking coccidia. As a result, the infection of coccidia becomes more severe (Lu et al., 2021).

Within the protozoan subgroup of the phylum Apicomplexa, *coccidia* comprises a diverse range of unicellular parasites. The coccidia belongs to the family *Eimeridae*, genus *Eimeria (E.)*, that is unique to a single host species or a group of closely related hosts (Müller and Hemphill, 2013).

Numerous *Eimeria* species have been isolated from various quail species. These include *E. tsunodai*, *E. uzura*, *E. bateri*, and *E. fluminensis* (Norton and Peirce, 1971; Teixeira and Lopes, 2000; 2002; Teixeira et al., 2004; Berto et al., 2013; Al-Zarkoushi and Al-Zubaidi, 2021), as well as *E. taldykurganica* (Svanbaev and Utebaeva, 1973) from Japanese quails. *E. lophortygis* and *E. okanaganensis* were identified in California quails (Liburd and Mahrt, 1970). From mountain quail, *E. crusti*, *E. oreortygis*, and *E. isospora* were detected (Duszynski and Gutierrez, 1981), while *E. conturnicis* and *E. bateri* were identified in grey quail (Chakravarty and Kar, 1947). Moreover, *E. colini* (Fisher and Kelley, 1977), *E. lettyae*, and *E. dispersa* were described from bobwhite quail (Ruff, 1985), and also *E. tahamensis* was described from Arabian quails (Amoudi, 1987; Berto et al., 2013).

In Egypt, *E. tsunodai*, *E. uzura*, *E. bateri* (El-Morsy et al., 2016; Arafat and Abbas, 2018; Hassan et al., 2020; Ramadan et al., 2021; Waheeb et al., 2022), *E. minima* (Arafat and Abbas, 2018), *E. coturniria* (Otify, 1988), as well as *E. colini* and *E. bahli* (Ramadan et al., 2021), were recognized in domesticated Japanese quails.

In migratory quails (*Coturnix coturnix japonica*) trapped during migration season from the El-Behera (Edko and Rashid districts) and Damietta provinces of Egypt, *E. tsunodai*, *E. uzura*, and *E. bateri* were identified (Basiouny et al., 2017; Waheeb et al., 2022), as well as *E. colini* and *E. bahli* (Basiouny et al., 2017).

Table 1 illustrates the available Egyptian literature on the morphological and morphometric characteristics of the oocysts and/or sporocysts of the several *Eimeria* species in quails.

Table 1. The morphological and morphometric features of oocysts and sporocysts of the different *Eimeria* species in quails via the available Egyptian literature

Eimeria species	**Quail Species (**Common name)	**Feature**						**Reference**
		Shape of oocyst	**Range of size (L×W) µm**	**Polar granule**	**Micropyle**	**Shape Sporocyst**	**Shape Stieda body**	
E. bateri	*C. Coturnix japonica* (Japanese quail)/ domesticated or migratory	Subspherical or ovoid to ellipsoidal	20-28 × 13-20	+	-	Pear or ovoid shape	Nipple-like	Basiouny et al. (2017); Arafat and Abbas (2018); Ramadan et al. (2021); Waheeb et al. (2022);
E. uzura	*C. Coturnix japonica* (Japanese quail)/ domesticated or migratory	Ovoid to ellipsoidal	18-26 × 13.4-19	+	-	Fusiform or Ovoid to elongate	Crescent or half-moon or a piriform or knob-like	
E. tsunodai	*C. Coturnix japonica* (Japanese quail)/ domesticated or migratory	Subspherical to oval or spherical to ellipsoidal	15-24 × 14-18	+	+/-	Ovoid	Pyriform or nipple-like to triangular	
E. bahli	*C. Coturnix japonica* (Japanese quail)/ domesticated or migratory	Spherical to subspherical	16.7-17.5 × 16.8-17.6	-	+	Oval	Present	Basiouny et al. (2017); Ramadan et al. (2021)
E. colini	*C. Coturnix japonica* (Japanese quail)/ domesticated or migratory	Oval	24.15-24.2 × 20.4-20.6	+	-	Curved fusiform	Present	
E. minima	*C. Coturnix japonica* (Japanese quail)/ domesticated	Spherical to subspherical	15-17 × 15-16	+	-	Ovoid	Nipple-like	Arafat and Abbas (2018)

(L) Length, (W) Width, (*E*) *Eimeria*, (+) present, (-) absent, E: *Eimeria*

Life cycle

The life cycle of coccidia mainly consists of exogenous and endogenous stages (Norton and Chard, 1983). During the exogenous phase, the host excretes the unsporulated oocysts, which then undergo sporulation in response to environmental conditions, such as temperature, oxygen, and moisture. The sporulated oocyst contains sporocysts, each of which entails sporozoites. After the host ingests the sporulated oocysts through contaminated food and water, the endogenous stage begins inside the host, which involves asexual (schizogony) and sexual (gametogony) reproduction (Dalloul and Lillehoj, 2005; Gilbert et al., 2011; Quiroz-Castañeda and Dantán-González, 2015). During this stage, the sporulated oocysts are exposed to digestive enzymes, and excystation of oocysts occurs in the gizzard. The sporozoites are released then invade the epithelial cells, and develop into trophozoites.

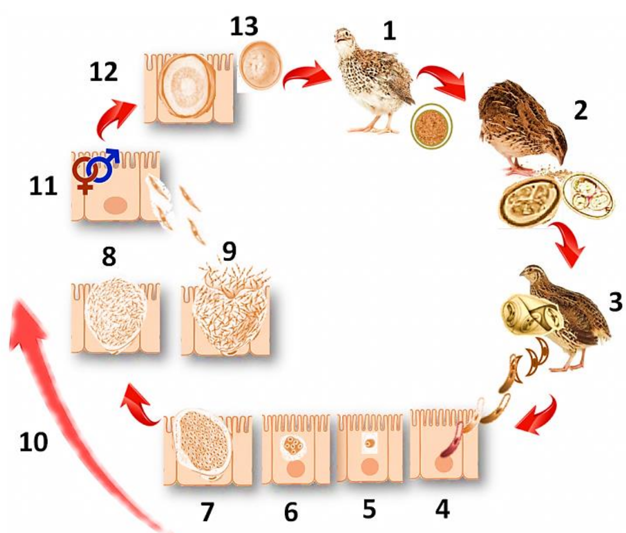

Figure 1. The life cycle of *Eimeria* in quails. 1: Shedding the mature unsporulated oocyst from quail. 2: Quail ingest the sporulated oocyst of *Eimeria bateri* and *Eimeria tsunodai*. 3: Releasing the sporozoites. 4: Invading the sporozoites into the epithelial cells. 5: Trophozoites. Both 6 and 7: Immature schizont. 8: Mature schizont. 9: Ruptured schizont and releasing merozoites. 10: Several asexual generations (schizogony). 11: Performing macrogametes (female) and microgametes (male) and occurring fertilization. 12: Developing oocysts. 13: Releasing the oocyst from the epithelial cells (modified from Conway and McKenzie, 2007)

The schizont begins replicating asexually, producing thousands of first-generation merozoites from each schizont.

Once the schizogony cycle is completed, the merozoites infect newly created epithelial cells in the intestinal lumen after the host cells are destroyed. Asexual reproduction occurs over several generations. Following that, the parasite replicates sexually and produces both macrogametes and microgametes. After macrogametes and microgametes fertilize each other to create zygotes, the zygote grows into an oocyst, which is then released into the environment along with fecal droppings (Ferguson et al., 2003; Shirley et al., 2005; Quiroz-Castañeda and Dantán-González, 2015). In this study, a diagram is designated by the authors using some individual parts from Conway and McKenzie (2007) to illustrate the life cycle of quail coccidiosis (Figure 1).

Clinical signs and gross pathological lesions

Several studies report the clinical findings in the quails infected with coccidia, and the Japanese quail is one of the most studied species. Under field conditions, mixed *Eimeria* species infections in quails are more common (Zoroaster et al., 2024). The most common clinical signs detected in the naturally infected quail include a lack of appetite, depression, anemia, emaciation, ruffled feathers, uncoordinated movements, diarrhea sometimes mixed with blood, and loss of weight, in addition to decreased egg production in laying quails (Teixeira et al., 2004; Simiyoon et al., 2018). These signs were more severe in young quails than in adults, which were more susceptible to coccidiosis infection (Teixeira et al., 2004). The pathological lesions vary depending on the type and location of *Eimeria*. According to Umar et al. (2014), cecal ballooning without any bloody exudate in the lumen is the primary pathological lesion in Japanese quails with a mixed *Eimeria* spp. infection. Two species of coccidia, *E. tsunodai* and *E. bateri* were shown to exhibit inflammatory changes in the cecum during post-mortem examination. These changes include dilated intestinal lumen, bloody intestinal contents, and mucosal lesions in Japanese quails (Sokół et al., 2015). The same cecal lesions were observed by Anbarasi et al. (2016) and Simiyoon et al. (2018).

In Egypt, abnormal intestines filled with bloody fecal material, as well as thickening of the intestinal mucosa with hemorrhage, were recorded in affected domesticated and migratory quails with a mixed infection of *E. bateri*, *E. uzura*, and *E. tsunodai* (Waheeb et al., 2022). The infection rates of various *Eimeria* species found in naturally infected domesticated or migratory quails in the Egyptian field are shown in Figures 2 and 3.

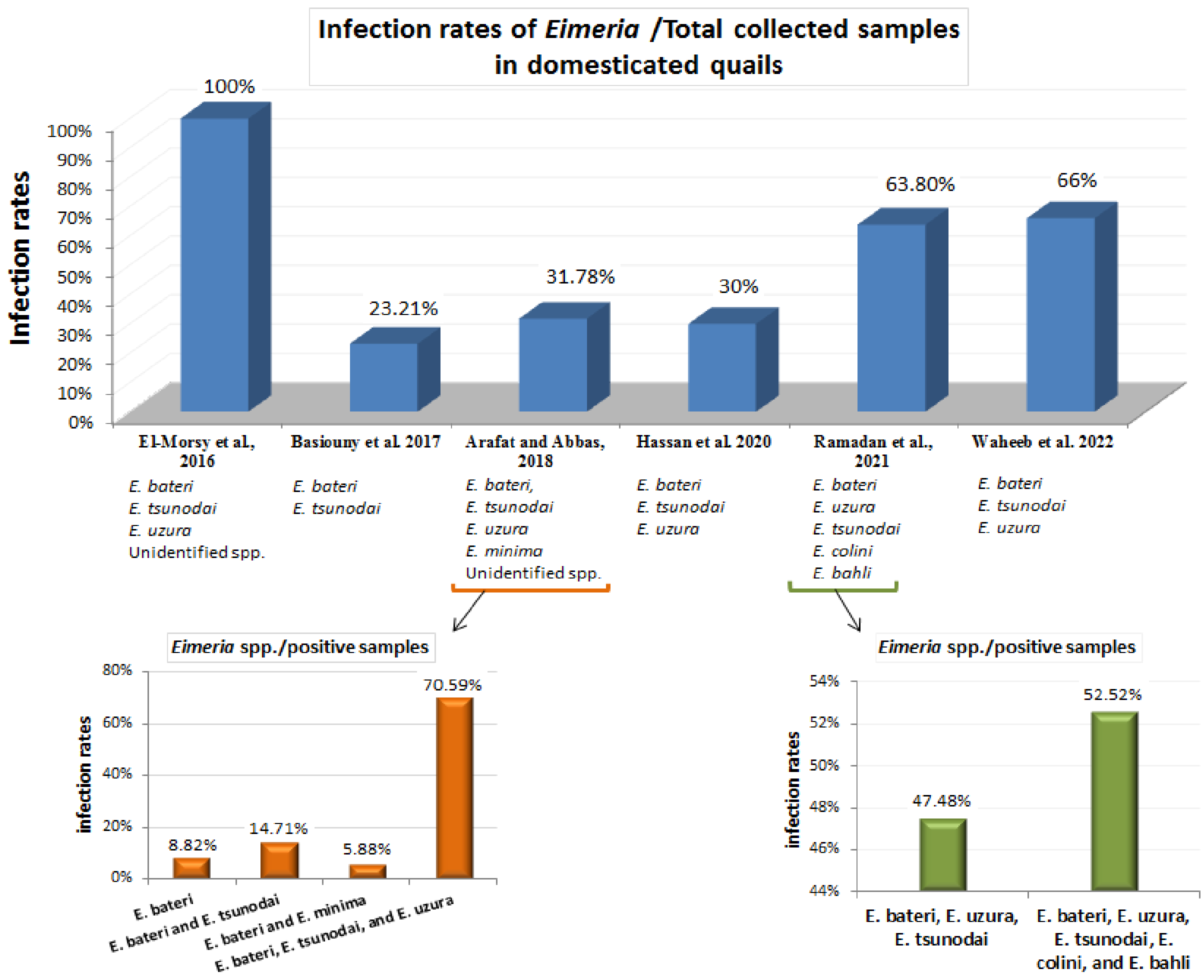

Figure 2. The infection rates of *Eimeria* species in naturally infected domesticate quail farms in Egypt. **Upper panel:** Infection rate (%) of *Eimeria* infection to the total collected samples either investigated individual quails or farms); **Lower panel:** Infection rate (%) of different *Eimeria* species to the positive samples

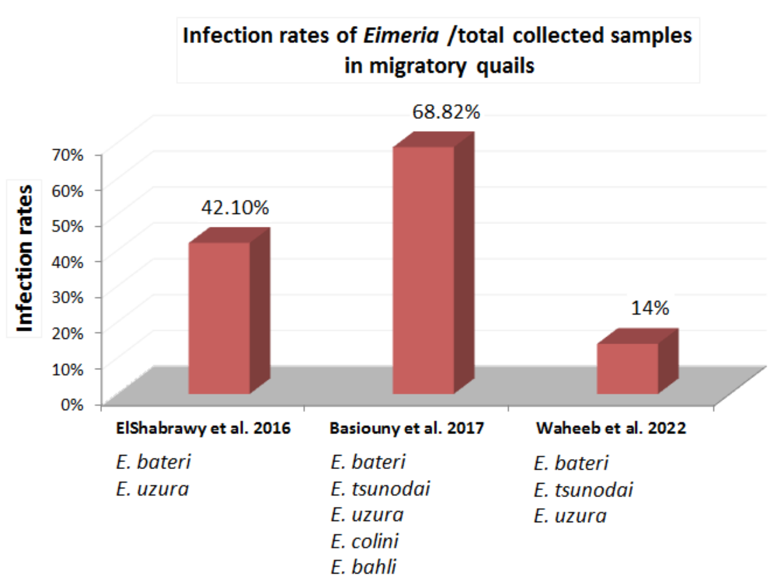

Figure 3. The infection rates of different *Eimeria* spp. in naturally infected migratory quails in Egypt

Regarding the experimental studies conducted on certain *Eimeria* species, anorexia, mild loss of weight, and softening of feces have been detected in the young Japanese quails experimentally infected with *E. bateri* (Norton and Pierce, 1971). Tsunoda and Muraki (1971) reported low pathogenicity of *E. uzura* in Japanese quails experimentally infected with 1×10^5 oocysts, and diarrhea and anemia were observed with no mortality.

Ruff and Wilkins (1987) investigated the effect of various doses of *E. lettyae* on bobwhite quails of different ages. They found that in 5-day-old bobwhites, a dose of 5×10^5 oocysts led to mortality rates ranging from 25% to 43%, while in 18-day-old bobwhites, there were no mortalities observed. In 5-day-old and 18-day-old bobwhites, a dose of 1×10^6 oocysts resulted in mortality rates of up to 100% and 83%, respectively. Body weight gain was significantly reduced in 5- and 18-day-old bobwhites infected with 1×10^5 and 5×10^5 oocysts or greater. Bobwhite inoculated with 5×10^5 oocysts or more exhibited typical signs of coccidiosis, including listlessness, droopiness, and anorexia with watery intestinal contents that were sometimes noticed. However, *E. lettyae* infection in mature bobwhite quails did not result in mortality; rather, it led to reduced egg production and fertility.

Under the investigations conducted in Egyptian studies, Arafa and Nasef (2004) recorded bloody diarrhea, low weight gain, and a mortality rate of 24% in infected Japanese quails with coccidia. El-Morsy et al. (2016) detected ruffled feathers, depression, decreased appetite, emaciated breast muscle, and bloody diarrhea in the Japanese quails experimentally infected with 4.1×10^4 oocysts of *E. tsunodai*. Additionally, severely enlarged and thickened mucosa of two ceca, a bloody cecal core, and ballooning were the most prominent lesions. On the other hand, Arafat and Abbas (2018) studied the pathogenicity of *E. bateri* in Japanese quails that were infected with various doses (10^2, 10^3, 10^4, and 10^5) of sporulated oocysts. They indicated that there were variable degrees of diarrhea, intestinal gross lesions, low weight gain, and food conversion rate (FCR) depending on the inoculated dose. The most severe signs and lesions were recorded in the quails infected with 10^4 and 10^5 doses of oocysts. Additionally, mortalities were recorded within 10% and 16.67% in groups inoculated with 10^4 and 10^5 oocysts, respectively. Emaciation, bloody diarrhea, and mortality rate reached 32% in Japanese quails experimentally infected with mixed oocysts of *E. bateri*, *E. uzura*, *E. tsunodai*, *E. colini*, and *E. bahli*. Additionally, observations revealed bloody cores and ballooning in the two ceca (Ramadan et al., 2021). There are variations in the signs, lesions, and severity, as well as the difference in the infection rate of the *Eimeria*, which could be attributed to the species of *Eimeria*, the oocyst infectious dose, the health status of birds, the type of rearing, and the environmental conditions. All data, diagnostic tools, obtainable clinical signs, and post-mortem lesions of natural and experimental infection with different *Eimeria* species in quails through the available Egyptian literature are demonstrated in Tables 2 and 3.

Histopathology lesions

The infection with *Eimeria* spp. mainly induces pathological changes in the intestine. Developmental stages of *Eimeria* spp. are mostly found in the duodenum, jejunum, and ileum. Commonly observed changes include severe necrotic enteritis, thickening of the epithelial cells, massive erosion in the small intestine, and hypertrophy of the villi with crypt enlargement (Teixeira and Lopes, 2002; Teixeira et al., 2004; Simiyoon et al., 2018; Al-Zarkoushi and Al-Zubaidi, 2021). Additionally, there is notable enterocyte degeneration and necrotic modifications, with enlarged cells occasionally containing parasitophorous vacuoles of protozoal developmental stages observed within intestinal villi. Furthermore, the parasitophorous uninucleated the epithelial cells and released free merozoites from enterocytes, primarily in crypts. The goblet cells in the crypt-mucosal epithelium and the spaces between the villus epithelial cells were filled with more mucin (Al-Zarkoushi and Al-Zubaidi, 2021). Moreover, significant inflammatory cell infiltration, including eosinophils, extending into the lamina propria and submucosa of the caecum, occasionally reaching the muscular coat and serosa, along with the presence of granulocytes and mononuclear cells, has been documented (Teixeira et al., 2004; Al-Zarkoushi and Al-Zubaidi, 2021). Furthermore, the caecum indicates an accumulation of micro- and macrogametes in the submucosa, as well as the desquamation of surface epithelium, lamina propria, and parasite vacuoles in the mucosal epithelium (Al-Zarkoushi and Al-Zubaidi, 2021).

Generally, the development stages of the *Eimeria* and the distraction in the epithelium cells of the intestinal mucosa and submucosa result in maldigestion and malabsorption accordingly, leading to economic losses due to weight loss and decreased productivity in the quail industry (Teixeira et al., 2004; Al-Zarkoushi and Al-Zubaidi, 2021). Within accessible Egyptian publications, several studies conducted field or experimental investigations utilizing microscopic examination as one of the diagnostic methods (Tables 2 and 3). Waheeb et al. (2022) detected hyperplasia of epithelial cells, desquamation of intestinal villi, and necrosis of intestinal epithelium alongside different developmental stages of parasites in naturally infected migratory and domesticated quails with *E. tsunodai*, *E. uzura*, and *E. bateri*. Additionally, severe intestinal inflammatory reactions with infiltration of eosinophilic and denuded villi, and severe damage of the cecal mucosa with cystic dilation of the submucosal gland of the cecal tonsil were observed as microscopic intestinal lesions in experimentally infected Japanese quails with sporulated oocysts of *Eimeria* spp. (Nasr El Deen et al., 2021).

Table 2. Diagnose of natural infection with different *Eimeria* species in domesticated and migratory quails in the available Egyptian literature

Total No. of investigated quails or farms	Species	Location	Methods of detection	Identified *Eimeria* spp.	Signs and lesions	Microscopic lesions	Reference
27 farms	Domesticated Japanese quail	Al-Dakahlia and Kafr El-Sheikh governorates	• Direct smear from fecal contents • Floatation technique under light microscope • Morphometric identification was done by using a calibrated ocular micrometer	*E. bateri* *E. tsunodai* *E. uzura* unidentified *Eimeria* species	—	—	El-Morsy et al. (2016)
190 live quails	Migratory quails (*Coturnix coturnix*)	Matrouh governorate	• Direct fecal smear • Sporulation of *Eimeria* oocysts	*E. bateri* *E. uzura*	• All birds were apparently healthy	—	ElShabrawy et al. (2016)
205 live quails	Domestic farm (n= 112) Migratory (*Coturnix coturnix japonica*) (n= 93)	The farm's ones from Sharkia governorate. Migrant quails from Rashid and Damietta cities.	• Direct fecal smear • Concentration floating method • Sporulation of *Eimeria* oocysts	**Migrant quails;** *E. bateri* *E. tsunodai* *E. uzura* *E. colini* *E. bahli* **Domestic quails;** *E. bateri* *E. tsunodai*	—	—	Basiouny et al. (2017)
107 examined farms	Young broiler (n= 71) Adult layer (n= 36)	Dakahlia, Damieta (North Delta), and Port Said (North coast), Egypt	• Simple and sugar flotation technique • The shape indices (length/width) of the sporulated oocysts (morphologically identified)	Four identified *Eimeria* spp *E. bateri*, *E. tsunodai*, *E. uzura*, and *E. minima* and unidentified *Eimeria* species	—	—	Arafat and Abbas (2018)
100 live quails	Domesticated quails	Assiut and El-menia governorates	• Sporulation of *Eimeria* oocysts with morphological differentiation • Unstained wet mount technique • Concentration technique	*E. bateri* *E. tsunodai* *E. uzura*	• Thickened intestinal wall	—	Hassan et al. (2020)
900 birds	Domesticated Japanese quail	Kalioubia governorate	• Morphological characteristics • Morphometric characteristics (dimensions) of oocysts	*E. bateri*, *E. uzura*, *E. tsunodai*, *E. colini, and E. bahli*	—	—	Ramadan et al. (2021)
100 live quails	Domesticated (n= 50) Migratory (*Coturnix coturnix japonica*) (n= 50)	El-Behera governorate (Edko and Rashid districts)	• Direct fecal smear • Simple floating method • Sporulation of *Eimeria* oocysts • Histopathology	*E. bateri* *E. tsunodai* *E. uzura*	• Abnormal intestine filled with bloody faecal material • Thickening of the intestinal mucosa with hemorrhage	• Hyperpalasia of epithelial cells with presence of different developmental stages of parasites (shizonts, macrogamets, and microgametes). • Desquamation of intestinal villi and necrosis of intestinal epithelium	Waheeb et al. (2022)

n: Number of quails collected from each species, —: Not mentioned.

Table 3. . Diagnose of experimental infection with *Eimeria* species in domesticated Japanese quails in the Egyptian literature

Type of infectious *Eimeria*	**Dose of infectious sporulated oocyst (Route)**	**Rearing system**	**Age of challenge**	**Experiment parameter**	**Clinical signs of positive control**	**Post mortem lesions of positive control**	**Microscopic lesions**	**Reference**
A field strain of quail's intestinal coccidiosis (Japanese quails)	6×10^4 (Orally)	Cages	21 days of age	• Mortality percentage • Body weight score • Total oocyst output	• Mortalities (24%) • Bloody diarrhea • Low weight gain • High lesion = 90 and intestinal *Eimeria* score reached to 4.6±0.9	—	—	Arafa and Nasef (2004)
E. tsunodai (Japanese quail)	4.1×10^4 (Intra crop)	Isolated sterilized wire floored rearing cages	14 days of age	• Clinical signs • Mortalities • Lesion scoring • Total oocyst output • Weight gain and FCR measurements	• Signs appeared at the 4th day post-infection • General signs of illness as ruffled feather, depression, huddling together, decreased appetite, emaciated breast muscle, and knife edged keel bone • Bloody diarrhea • Mortalities reached to 23.3%	• Severely enlarged two cecae with thickened mucosa • Bloody cecal core and ballooning	—	ElMorsy et al. (2016)
E. bateri (Japanese quail)	1ml of 10^2, 10^3, 10^4, and 10^5 sporulated oocysts (Orally)	Strict isolator/ wire floor cages	28 days of age	• Weight gain • FCR • Mortality • Severity of diarrhea (fecal score) • Intestinal lesion scores	• Diarrhea, low weight gain, and adverse effect on FCR varied in inoculated quails • More severe in groups infected with 10^4 and 10^5 • Mortalities were recorded only in 10^4 (10%) and 10^5 (16.67%)	• Gross lesion of the upper (duodenum and jejunum), lower (ileum), and cecum were different according to the dose level • More severe gross lesion in groups infected with 10^4 and 10^5	—	Arafat and Abbas (2018)
Mixed oocysts of *E. bateri*, *E. uzura*, *E. tsunodai*, *E. bahli* and *E. colini* (Japanese quail)	10^3 (—)	Isolated room	—	• Oocyst counting • Sporulation percentage • clinical signs • Body weight and mortalities. • Intestinal lesion	• General signs of illness • Mortalities 32% • Bloody diarrhea • Emaciation	• Bloody cecal core • Enlarged two cecai with ballooning	—	Ramadan et al. (2021)
Sporulated oocysts of *Eimeria* spp (Japanese quails)	4.1×10^4 (Intra crop)	—	14 days of age	• Histopathology • *Eimeria* oocyst count	—	—	• Severe intestinal inflammatory reaction with denuded villi and eosinophilic infiltration • Severe damage of the cecal mucosa caused by the proliferation of the parasites, meronts growth, and release of the merozoites with cystic dilation of the cecal tonsil submucosal gland	Nasr El Deen et al. (2021)

—: Not mentioned, FCR: Feed conversion ratio

Methods of diagnosis

Given the frequent occurrence of mixed infections in the field (Zoroaster et al., 2024), accurate differentiation between the different species of *Eimeria* remains challenging but necessary to obtain a prompt therapeutic or preventive intervention, particularly when the most dangerous species are circulating on the farm (Zoroaster et al., 2024).

Currently, the identification of *Eimeria* at the species level in quails relies on clinical and anatomopathological findings, coupled with the morphological characterization of mature oocysts and sporocysts using direct smear and floatation techniques under the light microscope (Duszynski and Wilber, 1997; Zoroaster et al., 2024), and morphometric characterization using a calibrated ocular micrometer (Henddrix and Robinson, 2012). These previously mentioned diagnostic methods were nearly used by all researchers to identify *Eimeria* spp. in quails (ElMorsy et al., 2016; Arafat and Abbas, 2018; Hassan et al., 2020; Ramadan et al., 2021; Waheeb et al., 2022). Only specialized laboratories with well-trained staff members can perform such time-consuming procedures (Zoroaster et al., 2024).

Previously, molecular tools were not commonly employed in diagnosing *Eimeria* species in quails due to limited information about the molecular characterization of the *Eimeria* species in quails, as well as the lack of available sequences in public databases (AL-Zarkoushi and AL-Zubaidi, 2022). In 2011, PCR-specific primers were specified and constructed against the internal transcribed spacer region 1 (ITS-1) of the ribosomal RNA gene to determine the prevalence of the different *Eimeria* spp. in captive game birds, such as northern bobwhite quails (Gerhold et al., 2011a). Analyses by PCR have targeted either the 18S rRNA (AL-Zarkoushi and AL-Zubaidi, 2022; Zoroaster et al., 2024) or the internal transcribed spacers (ITS1-5.8rRNA-ITS2) regions (Zoroaster et al., 2024). Moreover, the phylogenetic analysis of the 18S rRNA gene was performed on oocyst populations separately isolated from naturally infected Japanese quails (AL-Zarkoushi and AL-Zubaidi, 2022; Zoroaster et al., 2024). The nucleotide sequences of the 18s rDNA genes revealed the presence of seven genotypes of *Eimeria* spp. in Japanese quails (AL-Zarkoushi and AL-Zubaidi, 2022), while Zoroaster et al. (2024) inferred the potential presence of *E. uzura* based on their findings. Thus, molecular techniques have been pivotal in discerning the various genotypes of *Eimeria* species in animals.

Control and prevention

Trials of using anticoccidial drugs in quails

Several strategies for coccidiosis control include farm-level management techniques, vaccines, and natural and traditional anticoccidials (Shivaramaiah et al., 2014). To effectively manage coccidiosis in quail farms, appropriate control measures should be implemented, such as preventing water spills, maintaining high stocking density, disposing of litter regularly and hygienically, and enhancing hygiene standards (Umar et al., 2014).

Anti-coccidial medications, which prevent the sexual and asexual reproduction of *Eimeria* spp., are the main method of coccidiosis treatment (Odden et al., 2018). Using coccidiostats in feed or adding coccidiocidal drugs to the water were the most effective ways to control coccidiosis. Sokół et al. (2014) confirmed that Toltrazuril with different doses (7, 14, and 24.5 mg/kg body weight) could be an effective treatment of quail coccidia, but this effectiveness varied according to the species of coccidia and the parasitic developmental stages. Toltrazuril eliminates *E. bateri* and causes a high reduction in the number of *E. tsunodai* oocysts in the naturally infected Japanese quails.

In a study by Ruff et al. (1987) involving bobwhite quail infected with a mixed inoculum of *E. dispersa* and *E. lettyae* at a dose of 10^6 sporulated oocysts, the efficacy of salinomycin, amprolium, and monensin in preventing coccidiosis was examined. Based on body weight gains, the study found that both monensin and salinomycin were the most effective treatments for preventing coccidiosis. Monensin additionally reduced the number of parasites in the duodenum, while salinomycin decreased parasite numbers in both the duodenum and ileum at comparable rates. Furthermore, both anticoccidial drugs exhibited a reasonable safety margin in bobwhite quail. In contrast, amprolium was found to be ineffective in preventing coccidiosis (Ruff et al., 1987).

Furthermore, Gerhold et al. (2011b) detected that clopidol (125 ppm), decoquinate (30 ppm), diclazuril (1 ppm and 2 ppm), lasalocid (120 ppm), narasin (36 ppm), nicarbazin (36 ppm), robenidine (33 ppm), sulfadimethoxine/ormetoprin (125/75 ppm), and zoalene (150 ppm) have excellent to good efficacy with reducing lesion and fecal scores as well as improving weight gain and FCR in northern bobwhites experimentally infected with *E. lettyae*. However, monensin (90 ppm), salinomycin (60 ppm), semduramicin (25 ppm), or a combination of roxarsone and semduramicin were found to provide low protection. Amprolium (250 ppm), roxarsone (50 ppm), and zoalene (125 ppm) proved to be ineffective in controlling coccidia.

Several studies were conducted in Egypt to evaluate the efficacy of different anticoccidial drugs. In a study by El-Morsy et al. (2016), the efficacy of salinomycin and diclazuril as coccidia prophylactic feed additives was investigated in Japanese quails experimentally infected with *E. tsunodai* at a dose of 4.1×10^4 sporulated oocysts. The study also evaluated amprolium plus ethopabate and toltrazuril as coccidia water medicaments. The results indicated that water medicaments were significantly more effective compared to feed additive anticoccidials. Additionally, the mortality rate was low in groups treated with amprolium plus ethopabate, and toltrazuril had the least effect on the sporulation of oocysts.

Some studies evaluated the efficacy of natural products as an alternative anticoccidial to control quail coccidiosis and reached variable conclusions according to the kind of products, doses, duration, *Eimeria* spp., and quail species used in these experiments (Ahmadov et al., 2014; Asghar et al., 2020).

Among the Egyptian investigations on alternative anticoccidials, Nasr El Deen et al. (2021) examined alternative anticoccidials and compared the effectiveness of probiotics (products containing *Bacillus subtilis*, *Pediococcus pentosaceus*, *Pediococcus acidilactici*, *Lactobacillus acidophilus*, and *Saccharomyces cerevisiae*) and toltrazuril in treating coccidiosis in Japanese quails. The probiotics can be utilized as a possible substitute anticoccidial and effectively treat coccidiosis by reducing the quantity of *Eimeria* oocysts, minimizing the negative effects of free radicals, and increasing the levels of IFN-γ and IL-2 in the cecum. Ramadan et al. (2021) investigated the efficacy of Propolis and neem as natural anticoccidial products, compared to a chemical anticoccidial drug as amprol (amprolium hydrochloride and ethopabate), against the challenge of mixed infection of *E. bateri*, *E. uzura*, *E. tsunodai*, *E. colini*, and *E. bahli* in Japanese quails. The natural and chemical anticoccidial products reduced the symptoms, mortalities, intestinal lesions, and oocysts shedding. On the other hand, propolis achieved the highest body weight gain and the lowest percentage of oocyst sporulation in infected quails. The different trials that evaluated the efficacy of various chemical and alternative (herbal/probiotic) anticoccidials in Egyptian articles are mentioned in Table 4.

Experiments of immunization in quails' coccidiosis

Coccidiosis is usually controlled using live vaccines. The basic component of all vaccines prepared for poultry is sporulated oocysts from several species. There are various techniques for administering vaccines to chickens, such as spraying and applying gel droplets in diet or drinking water (Jenkins et al., 2012; Awad et al., 2013; Jenkins et al., 2013). To the authors' knowledge, a specific vaccine for *Eimeria* species in quail has not yet been produced or manufactured in Egypt. Available literature shows limited trials or investigations for immunization quails infected with coccidia.

In an attempt to immunize northern bobwhite quail at the age of two days, Gerhold et al. (2010) administered 100 or 1000 oocysts orally using a pipette. Four weeks after vaccination, 1×10^6 *E. lettyae* was given to the immunized quails as a challenge. Immunized quail showed a 50% lower FCR, fewer gross intestinal and cecal lesions, roughly 99.7% fewer oocysts, and decreased signs of diarrhea. Elmorsy et al. (2021a) found that the immunization with a 100-oocyst dose of *E. bateri*, *E. uzura*, and *E. tsunodai* separately at 2 days of age in Japanese quails yielded better results against a high-dose challenge, which was 4×10^4 oocysts of *E. tsunodai* and 1×10^5 oocysts of *E. bateri* and *E. uzura* at 2 weeks post-immunization. Moreover, Elmorsy et al. (2021b) evaluated the efficacy of immunization with a low dose of live sporulated cysts of different abovementioned respective *Eimeria* species separately in the Japanese quail, compared to the efficacy of amprolium plus sulphaquinoxaline. Depending on clinical signs, mortality, weight gain, FCR, oocyst output, lesion score, and hematological parameters, immunization against any isolated species achieved the best results regarding all tested parameters compared to amprolium plus sulphaquinoxaline.

In Egypt, Arafat and Abbas (2018) conducted an experiment where 2-day-old Japanese quails were challenged with 1×10^5 sporulated oocysts of *E. bateri* at 30 days old. They found that oral immunization with either 100 or 1000 sporulated oocysts of *E. bateri* reduced diarrhea, intestinal lesions, and oocyst production while also improving weight gain and FCR.

Table 4. Treatment trials of quail coccidiosis using different types of anticoccidial medications either chemical or alternative (herbal and probiotic)

Medication	Dose (Con.)	Route	Duration	Quail species	Infected		Parameters	Judgment	Reference
					***Eimeria* spp.**	**Dose (Age of infection)**			
Salinomycin	1 kg/ton (60 ppm)	Ration	48 hours before infection till 21 days post-infection	Japanese quail	*E. tsunodai*	4.1×10^4 (14 days)	• Clinical signs • Mortality rate • Lesion score • Body parameters (Body Weight, Body Weight Gain, and Feed Conversion Rate) • Count oocysts	• Diclazuril showed better results than salinomycin all tested parameters except both were showed the same lesion score with lower oocyst output in salinomycin • Amprolium and ethopabate had better results than toltrazuril in all tested parameters except the mortality rate was the same. • Coccidial water treatments were found to be more effective than prophylactic feed additives. • Toltrazuril had the lowest effect on sporulation of oocysts.	El-Morsy et al. (2016)
Diclazuril	200 gm/ ton (0.5%)	Ration	48 hours before infection till end exp.						
Amprolium and ethopabate	1 ml/liter (—)	Drinking water	5 days post-infection						
Toltrazuril	1ml /litter (25 ppm)	Drinking water	48 hours post-infection						
Amprol (amprolium hydrochloride and ethopabate)	20%	Drinking water	6^{th} day post-infection	Japanese quail	Mixed infection of *E. bateri, E. uzura, E. tsunodai, E. colini, and E. bahli*	10^3 (—)	• Oocysts counting • Sporulation percentage • Clinical signs • Intestinal lesion • Body weight • Mortalities	• Amprolium, Propolis, and neem had effect in reduction the counts of oocyst, signs, mortality rate, and inflammatory intestinal lesions. • Propolis had the highest effect in increasing the body gain, and declined the percentage of *Eimeria* oocyst sporulation in infected quails	Ramadan et al. (2021)
Propolis	20%	Drinking water							
Neem extract	20%	Drinking water							
Probiotic (Gro-2-max)	1 gm/liter	Drinking water	a day till 28 days old	Japanese quails	Sporulated oocysts of *Eimeria* spp.	4.1×10^4 (14 days)	• Blood biochemical analysis • Antioxidant enzyme activities • Immunological parameters (inflammatory markers; Cecal interferon-gamma (IFN-γ) and interleukin-2 (IL-2) using ELISA kits • Histopathology • *Eimeria* oocysts count	• Probiotic relatively minimize the oocysts shedding • Probiotic improvement in the cecal IFN-γ & IL-2 and antioxidant enzymes, which reduces the damage caused by free radicals	Nasr El Deen et al. (2021)
Toltrazuril	1 ml/ liter (25ppm)	Drinking water	16 days of age for 2 consecutive days						

Con: concentration, —: Not mentioned

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CONCLUSION

Reviewing the available literature on quail coccidiosis has indicated a range of symptoms from subclinical to clinical. Consequently, quail farms must be routinely examined to detect the infection and overcome its adverse consequences on quail productivity. The conventional tools used in detection and identification need to be developed due to the presence of an unknown *Eimeria* species in many studies. Thus, the molecular technique is a probable tool that needs to be introduced in the identification of unknown species besides the traditional tools. Due to the high prevalence of coccidia among quail farms, its control and prevention should be taken into consideration. There is an emerging need to find alternatives for chemical anticoccidial drugs as they have adverse effects on animal and human health. Further research into alternative anticoccidials and vaccinations should be conducted.

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Availability of data and materials

All the data supporting this study are present in the article. Any additional information needed is obtainable from the corresponding author upon justifiable request.

Authors' contributions

Amal A. M. Eid, Reham M. El Bakrey, and Sarah S. Helal were involved in the conception and design. Amal A. M. Eid, Reham M. El Bakrey, Sarah S. Helal, and Ahmed A. El Kholy carried out data collection and drafted the manuscript. Reham M. El Bakrey designated the figures. All authors read and approved the final edition of the manuscript.

Ethical considerations

The manuscript was examined by the authors for signs of plagiarism, permission to publish, misconduct, fraud or data manipulation, duplicate publication or submission, or redundancy.

Competing interests

The authors did not disclose any potential conflicts of interest.

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