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A Highlight on Avian Toxoplasmosis: One Health Disease with a Special Reference to the Current Egyptian Situation

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ABSTRACT

This review article was developed to the infection of avian species with *Toxoplasma gondii* (*T. gondii*), diagnosis, pet bird and human infection, and control methods with a special reference to the current status of infection among the Egyptian poultry farms and population. Toxoplasmosis is a zoonotic disease caused by a unicellular, protozoan parasite *T. gondii*. Different domesticated and wild animals, as well as birds can harbor *T. gondii* and may be a potential source of infection to humans. Avian species could be infected with *T. gondii* through the ingestion of contaminated food, soil, and water with oocysts shed in the excreta of infected animals, especially cats. Poor sanitation and hygienic conditions increase the risk of infection. Consumption of food or water, as well as undercooked poultry meat or meat products containing the oocysts of the parasite, are the main sources of human infection with *T. gondi*. Diagnosis of *T. gondii* in the infected host depends on the serological detection of specific antibodies and molecular detection of the parasite. Microscopic demonstration of the oocysts and other developmental stages of the parasite in the intestine, liver, brain, and skeletal muscles tissues is another means for rapid diagnosis. Generally, a high prevalence of the disease is also reported in pet birds. Toxoplasmosis in humans is associated with abortion, congenital disorders, stillbirth, and other complications, especially in immunocompromised patients. Application of hygienic measures, as well as public awareness, are essential for the prevention and control of toxoplasmosis. In different Egyptian governorates, a high prevalence of *T. gondii* has been detected in animals, birds, and humans. High incidence of infection was recorded due to the contact with *Toxoplasma* oocysts shed mainly from infected cats or other carriers. Egyptian chicken and turkey flocks and backyard birds revealed the presence of different developmental stages of the parasite and even its antibodies. In addition, human populations showed signs of toxoplasmosis with severe complications.

Keywords: Bird, Egypt, Human, *Toxoplasma gondii*, Zoonosis

INTRODUCTION

Toxoplasmosis is an important zoonotic parasitic disease of public health importance (CDC, 2004) and it is caused by an obligatory intracellular protozoan parasite, *Toxoplasma gondii* (*T. gondii*) (Tenter et al., 2000). The disease is of widespread nature and causes significant economic and reproductive losses in animals and serious public health problems in humans (Sukthana, 2006; Pan et al., 2017). Toxoplasmosis is a cosmopolitan zoonotic parasitic disease of nearly all warm-blooded mammals and birds. The infection rate with *T. gondii* in humans, animals, and birds is influenced by some epidemiological risk factors, such as age, sex, feeding pattern, and geographical distribution (Wilking et al., 2016; Zhang et al., 2016). Strains of *T. gondii* are transferred through continents mainly by stray cats and other animals, including migratory birds (Can et al., 2014). Most domestic and wild avian species showed infection with *T. gondii* (Ammar et al., 2020; Mikaeel and Al-Saeed, 2020; Lv et al., 2021). Avian species become infected with *T. gondii* through ingestion of the infective oocysts contaminated soil, food, and water (Ruiz and Frenkel, 1980; Dubey et al., 2008) as these oocysts may be shed in the feces of host animal's like cats (Yan et al., 2009). The oocysts of the parasite were detected in the liver, brain, and muscles of broiler chickens (Deyab and Hassanein, 2005; Amin et al., 2012). On the other hand, humans get infected with *T. gondii* through ingestion of undercooked chicken meat containing infective oocysts or other stages of the parasite (Zhang et al., 2016). However, spontaneous abortion, mental, and congenital disorders, as well as stillbirth and other complications were observed in people infected with *T. gondii* (Krueger et al., 2014; Egorov et al., 2018). Generally, the diagnosis of toxoplasmosis depends mainly on the detection of specific antibodies using serological tests (Li et al., 2020). Microscopic examination and molecular techniques such as Polymerase Chain Reaction (PCR) are other methods used for the diagnosis of toxoplasmosis (Barakat et al., 2012; Ibrahim et al., 2016a).

Egyptian environment enhances the infection and transmission of *T. gondii* due to the presence abundant number of domestic or stray cats that shed oocysts and contaminate the environment. Animals such as sheep, goats, and chickens

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are regarded as important intermediate hosts for *T. gondii* and their meat is the main source of the parasite to humans in case consumed unhygienically (El-Massey et al., 1990). Serological tests reveal the presence of *T. gondii* infections with a high prevalence rate either in animal or human populations. In addition, definitive diagnostic procedures of clinical cases with toxoplasmosis in Egypt are still required (Abbas et al., 2020). Regarding the infection of avian species with *T. gondii*, insufficient data are available. Therefore, this review article was developed to highlight the infection of avian species with *T. gondii*, diagnosis, pet birds and human infection, and control methods with a special reference to the current status of infection among the Egyptian poultry farms and population.

The protozoon parasite

There are three morphological stages of toxoplasmosis infection, namely an active multiplying tachyzoite stage, slowly multiplying semi-dormant bradyzoite stage in tissue cysts, and a sporozoite stage within oocysts that present in the environment (Ferguson, 2004; Al-Ammash et al., 2018). It has been reported that sporulated oocysts of *Toxoplasma* spp. can persist and survive in the environment for a long time and can infect all warm-blooded animals, birds, and humans (Frenkel, 2000; Sibley et al., 2009; Abdel-Shafy et al., 2015). Oocysts require 1 to 5 days to sporulate and become infective. Environmental conditions such as warm temperature or high humidity are essential for the survival of oocysts. It has been found that the incidence of toxoplasmosis is higher in humid tropical areas than in arctic areas (Meerburg and Kijlstra, 2009; Simon et al., 2013). Suitable environmental conditions, such as high temperature especially in spring, summer, and early autumn enhance the sporulation of *T. gondii* oocysts.

Genetic polymorphic classification of *T. gondii* strains is based on detection of three major clonal lineage types I, II, and III, additional lineage, and recombinant or atypical genotypes (Shwab et al., 2014; Lorenzi et al., 2016). Type II strains of *T. gondii* were common in Europe (Ajzenberg et al., 2002), while type II and III strains were detected in sub-Saharan and North Africa, the Middle East, and the Peninsula (Al-Kappany et al., 2010a; Dubey et al., 2010; Mercier et al., 2010). In addition, types I, II, and III of *T. gondii* and the recombinant strains were found in North and Central, and South America (Pena et al., 2008; Khan et al., 2011; Rajendran et al., 2012). In some Asian countries such as Iran, the three major clonal lineages of *T. gondii* were also detected (Zia-Ali et al., 2007; Chaichan et al., 2017).

Susceptibility of avian species to toxoplasmosis

Various domestic and farm animals, including birds, showed infection with *T. gondii* (Mose et al., 2016). Direct detection of *T. gondii* oocysts in the environment is difficult, so infected broiler chickens are regarded as an important indicator for severe environmental contamination and poor hygienic conditions in poultry farms (Dubey, 2010; Mahmood et al., 2014). World-wide infection of domestic avian species, such as chickens, turkeys, ducks, and pigeons, with *T. gondii* has been recorded and they are considered as important sources of humans' infection (Dubey, 2010; Guo et al., 2015).

The prevalence rate of *T. gondii* in backyard chickens was 65.1% in Rio de Janeiro (da Silva et al., 2003), 64% in Ghana (Dubey et al., 2008), 11.4% in China (Yan et al., 2009), and 38.4% in Ethiopia (Tilahun et al., 2013). In Iraq, Mohammed and Abdullah (2013) detected *T. gondii* in domestic chickens kept in the house in Sulaimania Province, while Mikaeel and Al-Saeed (2020) found a high prevalence rate of the parasite among free-range local chickens in Duhok Province, and this was indicative for heavy environmental contamination with the parasite. In the same context, some researchers indicated that the infection rate of *T. gondii* was more in free-range chickens when compared with cages reared birds in Nanjing region, China (Liu et al., 2017) and in Egypt (Ibrahim et al., 2009). Moreover, in Pakistan, it has been observed that domesticated chickens could harbor more *T. gondii* than broiler chickens kept in farms which may be attributed to frequent contact of domesticated birds with cats and ground feeding habits (Khan et al., 2020). Besides, broiler chickens kept in farms are reared under a controlled environment, have fast growth, and have low chances of contact with reservoir animals, such as cats (Krueger et al., 2014). The experimental challenge of turkeys with *T. gondii* was successful (Dubey et al., 1993b).

Some reports investigated the presence of toxoplasmosis in pigeons as well as their relation to public health (Dubey, 2002; Tsai et al., 2006). Free-flying birds such as pigeons may act as another reservoir or source of *Toxoplasma* infection for contact birds, animals, or humans (Biancifiori et al., 1986). Besides, successful experimental infection of pigeons with *T. gondii* has been conducted with induction of signs and death (Simitch et al., 1965).

Water fowls, including ducks and geese, are also susceptible to *T. gondii* infection. The first detection of fetal toxoplasmosis in domesticated ducks was in Argentina (Boehringer et al., 1962), then the disease was recorded worldwide in different countries (Zardi et al., 1967; Literák and Hejlícek, 1993; El-Massry et al., 2000). The prevalence's rates of *T. gondii* in ducks were recorded as 56% in Italy (Zardi et al., 1967) and 6% in Florida (Burridge et al., 1979), as well as 20% (Chen et al., 1986), 32.19% (Zhai et al., 1987), 23.33% (Zhang, 1989), and 3.93% (Lv, 1993) in China. Moreover, ToxoDB#9 genotype (Chinese I strain) was found to be predominant in ducks (Including 115 duck muscle samples, Zou et al., 2017). In China, *T. gondii* has been detected molecularly and serologically either in ducks (Lv et al., 2021) or geese (Rong et al., 2014).

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Successful oral infection of bobwhite quails (Dubey et al., 1993b) and Japanese quails (Dubey et al., 1994) with 49 strain of *T. gondii* oocysts has been reported. From the previous studies, the oocysts were re-isolated from the brain, heart, and muscles of the inoculated quails, moreover, antibodies to *T. gondii* were detected in quails for 63 days post-infection (PI) using an agglutination test. Experimental inoculation of quails with *T. gondii* tachyzoites revealed distribution and presence of this stage in the liver, lungs, and spleen at the day 7 PI, while the oocysts were detected in the brain and the heart of the birds on day 70 PI (Albuquerque et al., 2001).

Antibodies against *T. gondii* have been demonstrated serologically in ostriches in different localities of the world like Ghana (Dubey et al., 2000), Spain (Martínez-Díaz et al., 2002), Zimbabwe (Hove and Mukaratirwa, 2005), Brazil (Contente et al., 2009) and Egypt (El-Madawy and Metawea, 2013).

Wild birds are regarded as an important source and a reservoir for *T. gondii* for carnivores, besides, some of these birds are migratory and can spread the parasite worldwide (Nardoni et al., 2019). For instance, the prevalence rates of the parasite were 1% in doves, and 6.9% in the wild pigeon (Ammar et al., 2020), as well as 26.5% and 17.5% in sparrows of Iran (Khademvatan et al., 2013) and Brazil (Gondim et al., 2010), respectively. Moreover, the seroprevalences of *T. gondii* in broiler and layer chickens, pigeons, and sparrows using a random-effect model in Iran were 20%, 8%, and 15%, respectively (Shokri et al., 2017). In the same context, Amouei et al. (2018) serologically detected *T. gondii* in 51.4% of 385 free-ranging birds (chicken, ducks, and geese) and migratory birds (*Anas crecca*, *Anas platyrhynchos*, and *Fulica atra*).

Regarding the age's susceptibility, it has been reported that older hens were more susceptible to *T. gondii* than younger ones in the Thika Region of Kenya (Mose et al., 2016). A recent study by Lv et al. (2021) in China showed that ducks older than one year were more susceptible to the parasite than ducks younger than one year old.

Pathogenicity of parasite

Infection with *T. gondii* is mainly induced lesions in the liver and small intestine. The lesions are represented as congestion of the blood vessels and degenerative changes of the tissues. Congestion of the blood vessels is related to the ability of the parasite to pass from the intestine to the bloodstream and release some protein substances that destruct the blood platelets leading to increased vascular permeability and hemorrhages (Burney et al., 1999). The hyperplasia of the liver and the small intestine's cells were also reported (Amin et al., 2012). Infiltration of the parasite in the intestinal cells leads to apoptosis and deaths of some cells, while other cells show rapid regeneration and hyperplasia (Liesenfeld, 2002).

Diagnosis of toxoplasmosis

Rapid detection of the stages of *T. gondii* infection in avian hosts can be carried out through finding the parasites in stained impression smears or through histopathological sections of the affected organs (Dubey et al., 2007a; Dubey et al., 2007b; Ibrahim et al., 2016a). Moreover, *T. gondii* antigen could be detected using immunohistochemical staining techniques with polyclonal rabbit antibodies (Dubey et al., 2001). Intraperitoneal mouse inoculation (mouse bioassay) of *T. gondii* positive tissues should be done to obtain the tachyzoites stage (Dubey, 2010).

Diagnosis of *T. gondii* infection especially in birds is mainly based on the detection of specific antibodies using serological tests (Cabezón et al., 2011; Li et al., 2020). It has been reported that antibodies to *Toxoplasma* infection in cats could be detected within 3 weeks of infection and persisted in high titers for 5 years even in the absence of re-infection (Dubey, 1995). Enzyme-linked immunosorbent assay (ELISA), competitive-inhibition ELISA, indirect fluorescent antibody test (Nardoni et al., 2019), modified agglutination test (MAT) (Dubey, 2010; Alvarado-Esquivel et al., 2012; Rong et al., 2014), latex agglutination test (Raafat et al., 2011), Sabin-Feldman dye test (Literák and Hejlícek, 1993) and Western blotting are commonly used as serological techniques for the diagnosis of the disease (Huang et al., 2004). The most useful and commonly used serological test for the detection of *T. gondii* infection is MAT as it is specific, sensitive, does not require special equipment, and can be used for all avian species (Dubey, 2002). Tachyzoites of *T. gondii* could be maintained on monkey kidney adherent fibroblasts (Vero cells) cultures supplemented with 8% heat-inactivated fetal bovine serum for further serological detection (Ibrahim et al., 2016a).

The seroprevalences of *T. gondii* in domestic birds vary from one country to another according to the method used in testing, the number of the examined birds, and the type and the hygiene of breeding (Dubey, 2010). Many factor such as the locality, the number of birds, and the type and the hygiene of breeding affect the incidence or seroprevalences of *T. gondii* in domestic avian species (Dubey, 2010). For example, the seroprevalence of *T. gondii* antibodies among free-ranging chickens was 27.1% in Southern Iran (Asgari et al., 2008) and 40.4% in Giza Province of Egypt (Dubey et al., 2003a),

The molecular techniques for the diagnosis of *T. gondii* infection are based on the identification of immunodominant antigens using sera of animals infected with geographically distant isolates and from acute and chronically infected animals. In this regard, the surface antigen 2 of *T. gondii* (TgSAG2) which is expressed in *Escherichia coli* or the insect cells can be used as a useful, highly sensitive, and specific antigen for ELISA (Huang et

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al., 2002). Moreover, PCR is a specific, rapid, sensitive, and cost-effective technique that could be used for the detection of *T. gondii* DNA in chickens (Barakat et al., 2012). Howe et al. (1997) and Dubey et al. (2005) a fragment of 94 bp from the B1 gene of the parasite as a target to PCR amplification.

Toxoplasmosis in pet birds

Pet birds are usually kept in close contact with a human for companionship and entertainment. These birds play an important epidemiological role in the transmission and maintenance of many pathogens with public health significance for humans. Pet birds are bred in a semi-free-range system, so the birds have opportunities to contact food or water contaminated with *T. gondii* when they gather together. In addition, wild pet birds could transmit the protozoon in a long distance during flying and migration, and this transmission accelerated the spread of *T. gondii* diffusion. The role of pet birds in the transmission of *T. gondii* should be given more concern because they can serve as an important source of infection for cats (Ruiz and Frenkel, 1980; Dubey and Hamir, 2002). For instance, dead *T. gondii* infected pet birds from parks, pet shops or households are often un-hygienically disposed of and may be eaten by cats, and consequently, cats may become infected with the parasite and shed millions of oocysts. However, the transmission of *T. gondii* from pet birds to humans is not common as they are not bred for meat production (Boseret et al., 2013).

Up to now, some studies have been carried out to investigate the prevalence of *T. gondii* in psittacines and passerines species (Dubey, 2002; Hartley et al., 2008; Gazzonis et al., 2021). Fetal toxoplasmosis has been reported in parrots in Australia and New Zealand, psittacines in America, and budgerigars in Switzerland and the Netherlands (Dubey et al., 2004; Ferreira et al., 2012; Howe et al., 2014). In Brazil, the anti-*T. gondii* antibodies (IgY) were found in the serum of 71 adult blue-fronted Amazon parrots with a seropositivity rate of 9.8% (Marietto-Gonçalves et al., 2013). Besides, Andrade et al. (2016) serologically examined 67 different psittacine species and found anti-*T. gondii* antibodies in 1.3% of the examined birds. However, the recent investigation of Sato et al. (2020) revealed the absence of antibodies against *T. gondii* in wild red-tailed Amazon parrots. For the first time in China, the anti- *T. gondii* antibodies were found in 13.63% of Cockatiels and 3.85% of Lovebirds (Zhang et al., 2014). Further Chinese study of Cong et al. (2014) demonstrated that the seroprevalences of *T. gondii* were 11.65%, 11.39%, and 5.26% in Eurasian Siskin, Oriental Skylark, and Black-tailed Grosbeak, respectively, and these birds molecularly showed the presence of *T. gondii* B1 gene and type II variant (ToxoDB genotype #3). A virulent type II *T. gondii* strain has been isolated from a black-winged lory in North America (Dubey et al., 2004; Dubey et al., 2011), while type I/III variant *T. gondii* strain was demonstrated in Valley quail in Brazil (Casagrande et al., 2015). In Australia, based on histopathology, immunohistochemistry, and multilocus DNA typing findings, atypical type II genotype *T. gondii* strain was found in a pet peach-faced lovebird with nervous signs and lesions in the brain, spleen, liver, and heart (Cooper et al., 2015). Budgerigars are relatively resistant to clinical toxoplasmosis (Dubey and Hamir, 2002; Zhang et al., 2014). However, successful experimental infection of Budgerigars with *T. gondii* has been carried out (Kajerová et al., 2003). Before the identification of *Toxoplasma* species in 1908, the *Toxoplasma*-like parasite was detected in Java sparrows in the 1900s (Tenter et al., 2000), however, antibodies against *T. gondii* were detected in 34.29% of Java sparrows (Huang et al., 2019).

Toxoplasmosis in human

Recently, there is increasing attention to understand the main sources for human infection with toxoplasmosis (Dubey et al., 2008). Humans could be infected with *T. gondii* through ingestion of contaminated water or consumption of undercooked or raw poultry meat products containing infective oocysts or other stages of the parasite (Dubey and Jones, 2008; Dubey et al., 2010; Zhang et al., 2016). In addition, other problems such as congenital infection as well as blood transfusions and organs transplantation transmission methods have been reported (Tenter et al., 2000). Several factors are associated with infection of humans with *T. gondii* such as food handling and preparation hygiene, eating habits, levels of natural immunity, the oocysts contamination of the environment, and the level of contact with infected animals (del-Castillo and Herruzo, 1998; Swai and Schoonman, 2009).

It has been estimated that one-third of humans could be infected by *T. gondii* (Shokri et al., 2017) leading to different mental and congenital disorders, spontaneous abortion, and stillbirth (Krueger et al., 2014). In the United State of America, about 400-4000 infants are born with congenital toxoplasmosis having some complications like schizophrenia and obsessive-compulsive disorder (Egorov et al., 2018).

Toxoplasmosis is not commonly a significant problem for healthy people, however, it can be a life-threatening problem for congenitally infected young immuno-deficient patients, and primary infected pregnant women resulting in an acute or reactivated infection or even death (Pinard et al., 2003; Montoya and Liesenfeld, 2004; Remington et al., 2006). In Pakistan, the reports showed that the prevalence of *T. gondii* in the human population ranged from 12% to 28% (Majid et al., 2016; Latif et al., 2017; Nazir et al., 2017).

Toxoplasmosis in Egypt

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Identification of *T. gondii* infections either in humans, animals, and birds in Egypt is commonly based on serological and molecular techniques. The high prevalence of *T. gondii* infection in Egypt may be related to the presence of an abundant number of homeless cats that live on scraps of garbage to hunt for their food (Abbas et al., 2020). These cats are the main host and source of the parasite that heavily contaminate the environment with oocysts. Animals and birds can get the infection with *T. gondii* from this contaminated environment (Al-Kappany et al., 2010b). The main risk factor associated with *T. gondii* seropositive free-range and wild birds may be the contact with soil-harboring oocysts from street cats (Ibrahim et al., 2009). The high seroprevalence rate of *T. gondii* in free-range and cage chickens may be owing to the contact with soil-harboring oocysts shed from street cats (Ibrahim et al., 2009). Consumption of improperly cooked or grilled meat and meat products of domesticated animals (rabbits and poultry) is a major risk factor for Egyptians, especially those living in rural areas (Abou Elez et al., 2017).

From 2000 until 2020, the seroprevalences of *T. gondii* in birds were variable in different provinces of Egypt based on the geographical location, type of the collected samples, season, and the bird's species, age, and sex. Table 1 shows the incidences and the prevalence rates of *T. gondii* infections in different avian species from different provinces in Egypt in the period from 2000-2020.

Table 1. The incidences and the prevalence rates of *Toxoplasma gondii* infections in different avian species from different provinces in Egypt in the period from 2000-2020.

Species of birds	The findings	References
Commercial turkeys, chickens, and ducks	The MAT has been done to detect the presence of antibodies against *T. gondii* in the sera of 173 turkeys, 108 chickens, and 48 ducks from Giza, Egypt. The prevalence rateS of anti-*T. gondii* antibodies among turkeys, chickens, and ducks were 59.5%, 47.2%, and 50%, respectively.	El-Massry et al. (2000)
Commercial chickens	A high prevalence rate (40.4 %) of *T. gondii* in chickens from the rural area surrounding Giza (South of Cairo), Egypt was detected using MAT.	Dubey et al. (2003)
House-bred and farm-bred chickens	The seroprevalence of *Toxoplasma* antibodies was 30.0% (18 out of 60) in house-bred chickens, while it was 11.1% (10 out of 90) in farm-bred chickens by MAT in different Egyptian governorates. The histopathological examination of the tissues revealed lesions induced by *T. gondii* and the oocysts were detected in the liver, brain, heart, and skeletal muscles of 22 (78.6%) out of 28 positive chickens.	Deyab and Hassanein (2005)
Free-range and caged chickens	Serological detection of *T. gondii* specific antibodies, as well as tissue oocysts, showed positive percentages of 16.49 and 11.34 % in the free-range chickens and 8.69 and 4.83 % in the caged chickens, respectively in Delta provinces, Egypt.	Ibrahim et al. (2009)
Ducks	The prevalence of *T. gondii* was detected in ducks from Behera governorate, Egypt using MAT. The prevalence rate of the parasite was 13.9%. The highest prevalence was in the native breed (17.65%) and the 6-8-months age group (19.4%).	AbouLaila et al. (2011)
Quails	The presence of anti-*T. gondii* antibodies in the fecal and serum samples of native quails in Giza province, Egypt has been detected. It has been found that *T. gondii* antibodies prevalence rates were 29.8 and 25.5%, using MAT and LAT, respectively.	Raafat et al. (2011)
Free-range and commercial chickens	The seroprevalence rates of *T. gondii* in chickens of six Egyptian governorates were compared using ELISA. In addition, the presence of local *T. gondii* chicken strain was confirmed by PCR. The total prevalence rate was 68.8% comprised of 59.5%, 82.3%, 67.1%, 62.2%, 75%, and 50% in El Sharkia, El Gharbia, Kafr El sheikh, Cairo, Quena, and Sohag governorates, respectively. Moreover, the prevalence rates were higher among free-range (69.5%) than commercial farm chickens (68.5%); while the prevalence rate was less in upper Egypt than lower Egypt governorates and Cairo.	Barakat et al. (2012)
Free-range and farmed chickens	The seroprevalence of *T. gondii* infection in domestic chickens and humans in Beni-Suef province, Egypt was demonstrated. Serum samples of 215 (90 free-range and 125 farmed) chickens were examined using MAT. In addition, 250 sera samples were collected and examined for IgG using ELISA. The results showed 20% and 9.6% of antibodies of *T. gondii* in free-range and farmed chickens, respectively. However, antibodies to *T. gondii* were detected in 37.5% of poultry contact workers and in 30.5% of non-poultry contacts persons. Seroprevalence of 45.0 and 41.66% were observed among persons of ages 41-50 years and >50 years, respectively.	Aboelhadid et al. (2013)
Chickens	A total of 304 blood and brain samples were collected from chickens in the Delta provinces of Egypt. The prevalence rates of *T. gondii* infection were 11.18%, 6.91%, 6.91% using ELISA, histopathology, and immunohistochemistry methods, respectively. Moreover, significant differences in the prevalence of *T. gondii* were detected on the basis of season, sex and habitat.	Ibrahim et al. (2016a)
Ostriches	One hundred and twenty serum samples from ostriches in Ismailia province, Egypt were tested for anti- *T. gondii* antibodies using ELISA and MAT tests. Using enzyme immunoassay, 5 out of 120 birds (4.2%) were positive to IgM, while 11 birds (9.2%) were positive to IgG. However, MAT detected IgG in 15 birds (12.5%). The results of PCR revealed the presence of *T. gondii* DNA in the blood of 9 birds (7.5%). The results of PCR of the tissues showed positive *T. gondii* DNA in 5 dead birds either in the heart, brain, and thigh muscles.	El-Madawy and Metawea (2013)
Quails	One hundred samples were collected from 7-37 days old diseased quails in Assiut and El-Menia governorates, Egypt. The results of Giemsa-stained smears revealed the presence of *Toxoplasma's* tachyzoites in 7% of the examined samples.	Hassan et al. (2020)

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The seroprevalences of *Toxoplasma* infections in humans varied from 27 % to 68% in asymptomatic pregnant women (Ghoneim et al., 2010; El Deeb et al., 2012; Ibrahim et al., 2016b), 26% in cerebrospinal fluid of patients with meningoencephalitis (Mabrouk and Dahawi, 1991), and 59.6% in blood donors without signs (Elsheikha et al., 2009). It has been reported a higher percentage of toxoplasmosis among Egyptians with liver cirrhosis (El-Henawy et al., 2015; El-Sayed et al., 2016). In the Province of Sharkia, Egypt, Mostafa et al. (2018) demonstrated a significant correlation between the seroprevalence of *T. gondii* in patients and the presence of different types of tumors as breast cancer, bone's squamous cell carcinoma, and brain tumors. Anti-*Toxoplasma* IgG was found in patients with liver tumors and bladder cancer, while IgM was detected in patients with benign uterine tumors, bone carcinoma, and breast cancer. In addition, *T. gondii* oocysts were detected in immuno-stained brain sections. In another study revealed a significantly higher proportion of seropositive anti-*Toxoplasma* IgG antibodies among type I diabetes mellitus patients (45%) compared with the control group (23.3%) (Khattab et al., 2019).

Prevention and control of toxoplasmosis

Estimation of zoonotic diseases in animals and birds is helpful for monitoring and improving public health in humans. Therefore, a definitive diagnosis of *Toxoplasma* infection in animals is necessary to prevent human zoonose infection (AbouLaila et al., 2011). Definitive diagnosis of zoonotic diseases with public health concerns, such as toxoplasmosis is very helpful for the prevention of human infection (AbouLaila et al., 2011).

Consumption of insufficiently cooked meat of birds should be avoided as well as fecal contamination from birds should be controlled (Raafat et al., 2011). Nardoni et al. (2019) demonstrated the wide distribution of *T. gondii* in game and wild birds and advised accurate estimation of the human infection risks in handling, managing, and eating wild bird species with regard to domestic carnivores and the impact of viscera or offal's in the environment.

Free-ranged and farmed chickens are regarded as a potential risk to the contact resident persons, so, application of strict preventive hygiene measures is a must to avoid transmission of *T. gondii* infection from birds to humans (Aboelhadid et al., 2013; Mikaeel and Al-Saeed, 2020).

It is very essential to implement a high level of education and awareness among populations to reduce the prevalence of toxoplasmosis (Jones et al., 2001). Consumption of undercooked animal products or unwashed raw vegetable/fruit, poor hands hygiene, and un-carful contact with soil, farm animals, and birds should be avoided (El Deeb et al., 2012). Furthermore, periodic exclusion diagnosis of toxoplasmosis in patients with chronic diseases should be done to avoid the possibility of increasing the disease's severity and for possible management of these malignancies.

CONCLUSION

Toxoplasmosis represents a complex problem, not only for animals and birds but also for human health, especially under Egyptian conditions. However, the current situation of avian toxoplasmosis in Egypt still needs more investigation. Therefore, periodical detection of toxoplasmosis prevalence's in living birds or in their products as well as application of hygienic measures in poultry farms are important to avoid the possibility of zoonotic transmission. In addition, periodical testing and examination, as well as public health awareness of human populations, are very critical.

DECLARATIONS

Competing interests

The author has not declared any conflict of interest.

Ethical considerations

Plagiarism, consent to publish, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been checked by the author.

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