



Tick-borne diseases in Egypt: A one health perspective

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ABSTRACT

Background: Ticks are important arthropod vectors that transmit pathogens to humans and animals. Owing to favourable climatic and environmental conditions, along with animal importation from neighbouring countries, ticks and tick-borne diseases (TBDs) are widespread in Egyptian localities. Here, we review the current knowledge on the epidemiology of TBDs in Egypt in light of the One Health paradigm.

Methods and results: Five scientific databases, including “Web of Science”, “Scopus”, “PubMed”, “Science Direct”, and “Google Scholar”, were searched for articles describing TBDs in Egypt. A total of 18 TBDs have been reported in humans and animals, including three protozoal diseases (babesiosis, theileriosis, and hepatozoonosis), 12 bacterial diseases (anaplasmosis, ehrlichiosis, Lyme borreliosis, bovine borreliosis, tick-borne relapsing fever, Mediterranean spotted fever, African tick-borne fever, lymphangitis-associated rickettsiosis, bartonellosis, tularaemia, Q fever, and aegyptianellosis), and three viral diseases (Crimean-Congo haemorrhagic fever, Alkhurma haemorrhagic fever, and Lumpy skin disease).

Conclusions: Despite the circulation of zoonotic tick-borne pathogens among livestock and tick vectors, human infections have been overlooked and are potentially limited to infer the actual communicable disease burden. Therefore, facility-based surveillance of TBDs, combined with capacity building for laboratory diagnostics in healthcare facilities, is urgently required to improve diagnosis and inform policy-making in disease prevention. Additionally, collaboration between expert researchers from various disciplines (physicians, biologists, acarologists, and veterinarians) is required to develop advanced research projects to control ticks and TBDs. Considering that domestic livestock is integral to many Egyptian households, comprehensive epidemiological studies on TBDs should assess all disease contributors, including vertebrate hosts (animals, humans, and rodents) and ticks in the same ecological region, for better assessment of disease burden. Additionally, upscaling of border inspections of imported animals is required to stop crossover movements of ticks and TBDs.

1. Introduction

Ticks are hematophagous arthropods that parasitise most vertebrates, including humans and animals, worldwide [1]. Considering that ticks harbour and transmit various pathogens posing threats to humans and animals, they rank second to mosquitoes as a significant vector for human vector-borne diseases. Additionally, tick bites can cause irritation, severe allergies, or paralysis [2,3]. Tick-borne pathogens encompass various bacteria, viruses, helminths, and protozoa and have further diversified over the past few decades [4]. Globally, the ongoing geographic range of tick species is rapidly expanding, possibly driven by climate, demographics, ecology, and increased movement of humans and global trade of animals, resulting in the resurgence and

redistribution of infectious and zoonotic diseases [5].

Located on the southern coast of the Mediterranean Sea, Egypt is positioned on an internationally important migration route (African–Eurasian flyway) for birds migrating between their breeding grounds in Eurasia and their wintering grounds in Africa [6]. Millions of birds, including many European migrants, pass across the Mediterranean Sea in spring and autumn, providing opportunities for dispersal of ticks and their associated pathogens [7–9]. Migratory birds crossing Egypt have different tick species and subspecies, including *Ixodes redikorzevi*, *Ixodes ricinus*, *Ixodes frontalis*, *Haemaphysalis inermis*, *Hyalomma rufipes*, *Hyalomma marginatum*, *Hyalomma impeltatum*, *Hyalomma anatolicum*, *Hyalomma excavatum*, *Ha. punctata*, *Amblyomma variegatum*, *Hyalomma aegyptium*, *Hyalomma dromedarii*, *Rhipicephalus sanguineus*,

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and *Argas* sp. [7–9]. The immature stages of different ticks collected from birds suggest that many of them were carried and disseminated into Europe, Asia, and Africa [7–9].

Furthermore, the geographic location of Egypt results in a prevailing dry equatorial climate, except for the northern coastal areas, where a moderately warm climate dominates. Egypt's climate is characterised by hot dry summers and moderate winters with increasing coldness and rainfall along the Red Sea and Mediterranean Sea coasts [10]. These conditions provide a conducive environment for the growth of various species, including ticks and tick-borne pathogens [11–13]. Many tick-borne pathogens can endanger human and animal welfare and livestock husbandry, causing emerging or re-emerging zoonotic diseases.

The importation of animals infected with TBDs from endemic sub-Saharan African countries poses threats to humans and animals [14]. Camels and cattle imported from Sudan are quarantined at Abu Simbel or Shalateen in southern Egypt, while those imported from Ethiopia are quarantined at the Adabiya port, Al Qata (Giza governorate), or Sahl Hasheesh (Red Sea governorate). Subsequently, animals released from quarantine are transported to slaughterhouses or animal markets, which are generally located in populated areas, where the risk of transmission of ticks and TBDs is much higher [14].

Egypt is a northeast African country with a population of over 100 million people and 28 million livestock [15,16]. The livestock sector accounts for 40% of the agricultural gross domestic product and serves as a primary source of meat, milk, farm labour, and livelihood for most of the country's population. Egypt is currently divided into 27 governorates, namely four city governorates (Cairo, Alexandria, Port Said, and Suez), with nine located in Lower Egypt (in the Delta), nine in Upper Egypt along the Nile River extending from Cairo to Aswan, and five covering the Sinai Peninsula and western and eastern deserts [16].

Ticks have been reported to exist in ancient Egypt; a recent archaeological study of a mummified dog dating back to the Roman period showed evidence of significant infestation by the brown dog tick *Rh. sanguineus* [17]. To date, approximately 52 tick species have been identified in Egypt. Of these, eight species belonging to the Argasidae family were recovered from birds, foxes, rodents, and hedgehogs in different Egyptian localities: *Ornithodoros savignyi*, *Ornithodoros salahi*, *Ornithodoros erraticus*, *Ornithodoros tholozani*, *Ornithodoros arenicolous*, *Argas hermanni*, *Argas persicus*, and *Argas arboreus* [18–23]. Additionally, 44 tick species belonging to the Ixodidae family have been reported to infest livestock in Egypt, including *Amblyomma eburneum*, *Amblyomma gemma*, *Amblyomma hebraeum*, *Amblyomma lepidum*, *Amblyomma marmoreum*, *A. variegatum*, *Haemaphysalis erinacei*, *Ha. inermis*, *Haemaphysalis leachi*, *Haemaphysalis parva*, *Haemaphysalis punctata*, *Haemaphysalis sulcata*, *Hy. aegyptium*, *Hyalomma albiparvum*, *Hy. anatolicum*, *Hy. dromedarii*, *Hy. excavatum*, *Hyalomma franchinii*, *Hy. impeltatum*, *Hyalomma impressum*, *Hyalomma lusitanicum*, *Hy. marginatum*, *Hy. rufipes*, *Hyalomma schulzei*, *Hyalomma scupense*, *Hyalomma truncatum*, *Hyalomma turanicum*, *Ixodes kaiseri*, *I. redikorzevi*, *Rhipicephalus annulatus*, *Rhipicephalus appendiculatus*, *Rhipicephalus bursa*, *Rhipicephalus camicasi*, *Rhipicephalus decoloratus*, *Rhipicephalus evertsi*, *Rhipicephalus guilhoni*, *Rhipicephalus humeralis*, *Rhipicephalus muhsamae*, *Rhipicephalus praetextatus*, *Rhipicephalus pulchellus*, *Rhipicephalus rossicus*, *Rh. sanguineus*, *Rhipicephalus simus*, and *Rhipicephalus turanicus* [24,25].

The burden of TBDs owing to their impact on public health and the livestock industry is considerably underestimated and can overwhelm economic conditions and health systems in developed countries, including Egypt [26]. Among TBDs, babesiosis, theileriosis, anaplasmosis, rickettsiosis, ehrlichiosis, and borreliosis have been reported in different governorates of Egypt. Disruption of the transmission chain involving the vertebrate host and ticks is a major challenge in the prevention and control of TBDs [3]. Therefore, the One Health paradigm has been suggested as a relevant approach to combat TBDs [27,28]. It recognises the interconnection among humans, animals, and environmental health; promotes transdisciplinary and multisectoral

collaborations; and provides an important approach in confronting zoonotic diseases. Accordingly, veterinarians, physicians, ecologists, and public health professionals should collaborate to identify the vector and tick-borne pathogens in order to develop control strategies for TBDs.

Here, we review the current knowledge on the epidemiology of TBDs in Egypt. In addition, we identify gaps in knowledge regarding the epidemiology of TBDs and provide recommendations to implement the One Health approach in Egypt.

2. Methods

We searched five scientific databases, namely “Web of Science”, “Scopus”, “PubMed”, “Science Direct”, and “Google Scholar”, to collect the research articles relevant to our topic “ticks and TBDs in Egypt”. The following combinations of search terms were used: “ticks” AND “TBDs” AND “tick-borne pathogens” AND “*Babesia*” AND “*Theileria*” AND “*Anaplasma*” AND “*Rickettsia*” AND “*Borrelia*” AND “*Ehrlichia*” AND “*Bartonella*” AND “*Francisella*” AND “Alkhurma haemorrhagic fever” OR “Crimean-Congo hemorrhagic fever” AND “Egypt.” Articles published in English or Arabic until April 2022 were included in this study. The included articles were also screened for additional data concerning the local distribution within Egyptian governorates (Table 1). Duplicate articles or articles reporting ticks and tick-borne pathogens in other countries were excluded.

3. Results

In Egypt, 18 TBDs of humans and animals have been reported, including three protozoal diseases (babesiosis, theileriosis, and hepatozoonosis), 12 bacterial diseases (anaplasmosis, ehrlichiosis, Lyme borreliosis, bovine borreliosis, tick-borne relapsing fever [TBRF], Mediterranean spotted fever, African tick-borne fever, lymphangitis-associated rickettsiosis, bartonellosis, tularaemia, Q fever, and aegyptianellosis), and three viral diseases (Crimean-Congo hemorrhagic fever [CCHF], Alkhurma haemorrhagic fever [AHF], and Lumpy skin disease [LSD]). Additionally, a number of arboviruses have been reported, but the resulting diseases are unknown (Table 1).

Approximately 119 epidemiological studies on animal and human TBDs in Egypt are currently available (Table 2). Most studies (77/119; 64.6%) involved animals, whereas a few studies (18/119; 15.1%) involved humans. Further, 14 (11.8%) studies reported the pathogens in ticks and 10 (8.4%) studies reported the pathogens in both animals and ticks (Table 2). Regarding human infections, ten (10/18; 55.6%), six (6/18; 33.3%), and one study included serologic, genetic, and combined serologic and molecular diagnoses, respectively. Another study was based on blood film examination. Additionally, several species of tick-borne pathogens have been molecularly confirmed by more than one study, including *Babesia bovis*, *Babesia bigemina*, *Babesia occultans*, *Babesia caballi*, *Babesia canis vogeli*, *Theileria annulata*, *Theileria ovis*, *Theileria equi*, *Theileria lestoquardi*, *Anaplasma marginale*, *Anaplasma centrale*, *Anaplasma ovis*, *Anaplasma platys*, *Anaplasma platys*-like, *Anaplasma phagocytophilum*, *Ehrlichia canis*, *Rickettsia africae*, *Borrelia burgdorferi*, *Borrelia theileri*, *Coxiella burnetii*, AHFV, and CCHFV (Table 2).

3.1. Protozoal diseases

3.1.1. Babesiosis

Babesiosis is a zoonotic disease of animals and humans caused by infection with intraerythrocytic protozoan parasites of *Babesia* sp. and transmitted primarily by ixodid ticks [144]. Six primary species have been identified as causative agents of human infections, including *Babesia microti*, *Babesia duncani*, *Babesia divergens*, *Babesia motasi*, *Babesia venatorum*, and *Babesia crassa*-like agent [145]. Human babesiosis is usually asymptomatic and self-limiting in healthy individuals. Common mild flu-like symptoms of human babesiosis include fever, headache, chills, fatigue, inappetence, and shortness of breath [146].

Table 1
Tick-borne diseases, tick vectors, and their geographical distribution within Egypt.

TBDs and etiological agent	Species	Host	Primary/probable tick vector	Geographical distribution	Reference
Babesiosis	<i>Babesia bovis</i>	Buffaloes, camels, cattle, sheep	<i>Rhipicephalus annulatus</i>	Assiut, Beheira, Cairo, Dakahlia, Elminia, Fayoum, Giza, Halayeb, Kafr Elsheikh, Matrouh, Menofia, New valley, Port Said, Qena, Shalateen, Sharkia, Sohag	[29–34]
	<i>Babesia bigemina</i>	Buffaloes, camels, cattle	<i>Rhipicephalus annulatus</i>	Beheira, Benisuef, Dakahlia, Elminia, Fayoum, Giza, Ismailia, Kafr Elsheikh, Matrouh, Menofia, New valley, Qena, Qalyobia, Sharkia, Sohag	[30,32,43–47,35–42]
	<i>Babesia ovis</i>	Camels, cattle, goats, sheep	ND	North Sinai, Siwa Oasis	[48,49]
	<i>Babesia occultans</i>	Buffaloes, cattle	<i>Hyalomma excavatum</i>	Assiut, Elminia, Fayoum, New valley	[33,40]
	<i>Babesia caballi</i>	Donkeys, horses	ND	Alexandria, Benisuef, Cairo, Fayoum, Giza, Ismailia, Kafr Elsheikh, Menofia, Qalyobia	[50,51]
	<i>Babesia equi</i>	Horses	ND	ND	[52]
	<i>Babesia canis vogeli</i>	Dogs	ND	Cairo, Giza	[46,53–55]
	<i>Babesia behnkei</i>	Rodents	ND	Sinai	[56]
	<i>Babesia</i> sp.	Cattle, humans, rodents	ND	Cairo, Menofia, Qena, Sinai	[57–62]
	Hepatozoonosis	<i>Hepatozoon canis</i>	Dogs	ND	Cairo, Giza
<i>Hepatozoon</i> sp.		Rodents	ND	Sinai	[62]
Theileriosis	<i>Theileria annulata</i>	Buffaloes, camels, cattle, sheep	<i>Hyalomma dromedarii</i> , <i>Hyalomma excavatum</i>	Aswan, Beheira, Benisuef, Dakahlia, Elminia, Fayoum, Giza, Menofia, New valley, Port Said, Qena, Qalyobia, Sharkia, Sohag	[33,36,70–74,43,46,47,65–69]
	<i>Theileria ovis</i>	Buffaloes, camel, cattle, equines, goats, sheep	ND	Aswan, Beheira, Benisuef, Cairo, Giza, Menofia, New valley, Qalyobia, Sinai	[46,49,66,70,72,75–77]
	<i>Theileria equi</i>	Donkey, horses, mules	<i>Rhipicephalus annulatus</i>	Alexandria, Benisuef, Cairo, Fayoum, Giza, Ismailia, Matrouh, Menofia	[51,75,78–82]
	<i>Theileria lestoquardi</i>	Buffaloes, sheep	ND	Beheira, Giza, Menofia, New valley, Upper Egypt	[66,72,76,77]
	<i>Theileria haneyi</i>	Donkeys, horses	ND	Alexandria, Benisuef, Cairo, Fayoum, Giza, Ismailia, Menofia	[80]
	<i>Theileria orientalis</i>	Buffaloes, cattle	ND	Beheira, Menofia	[36]
	<i>Theileria uilenbergi</i>	Buffaloes	ND	Upper Egypt	[72]
	<i>Theileria mutans</i> -like,	Camels	ND	Aswan	[70]
	<i>Theileria separata</i>				
	<i>Theileria africa</i>	Equines	ND	Benisuef, Cairo	[75]
Anaplasmosis	<i>Anaplasma</i> sp.	Camels, cattle	<i>Hyalomma dromedarii</i>	Menofia, Upper Egypt	[61,70,83]
	<i>Anaplasma marginale</i>	Buffaloes, camels, cattle, equine, sheep	<i>Hyalomma excavatum</i> , <i>Rhipicephalus annulatus</i>	Assiut, Beheira, Benisuef, Cairo, Dakahlia, Damietta, Elminia, Fayoum, Gharbia, Giza, Kafr Elsheikh, Matrouh, Menofia, New valley, Qena, Qalyobia, Sinai, Sohag	[33,34,85–87,37,38,40–43,46,75]
	<i>Anaplasma centrale</i>	Camels, cattle	ND	Beheira, Benisuef, Cairo, Giza, Matrouh, New valley, Qalyobia, Sinai	[37,46].
	<i>Anaplasma ovis</i>	Cattle, equine, sheep	ND	Alexandria, Benisuef, Cairo, Gharbia, Kafr Elsheikh, Menofia	[42,46,75,88]
	<i>Anaplasma platys</i>	Buffaloes, camel, cattle, dogs	<i>Hyalomma excavatum</i> , <i>Rhipicephalus annulatus</i> , <i>Rhipicephalus sanguineus</i>	Assiut, Benisuef, Cairo, Elminia, Fayoum, Giza, New valley, Qalyobia, Sinai	[33,40,46,89,90].
	<i>Anaplasma platys</i> -like	Buffaloes, camel, cattle, sheep	<i>Rhipicephalus annulatus</i>	Beheira, Benisuef, Cairo, Giza, Menofia, New valley, Qalyobia, Sinai	[42,46,75]
	<i>Anaplasma</i> sp.	Buffaloes, camel, cattle, dogs	<i>Rhipicephalus annulatus</i>	Aswan, Beheira, Benisuef, Cairo, Giza, Menofia, New valley, Qalyobia, Sinai	[42,70,91,92]
	<i>Candidatus Anaplasma cameli</i>	Camel	ND	Aswan	[70]
	<i>Anaplasma phagocytophilum</i>	Dogs, humans, sheep	<i>Rhipicephalus sanguineus</i>	Giza, Nile Delta	[93–95]

(continued on next page)

Table 1 (continued)

TBDs and etiological agent	Species	Host	Primary/probable tick vector	Geographical distribution	Reference
Aegyptianellosis	<i>Aegyptianella pullorum</i>	Chickens	<i>Argas</i> sp.	ND	[21,84]
Bartonellosis	<i>Bartonella</i> sp.	Cats, cattle, humans, rodents	ND	Fayoum, Menofia, Sinai	[62,96–99].
	<i>Bartonella elizabethae</i> , <i>Candidatus</i> <i>Bartonella fadhilae</i> , <i>Candidatus</i> <i>Bartonella sanaae</i>	Rodents	ND	Sinai	[100–102]
Borreliosis					
Lyme boreliosis	<i>Borrelia burgdorferi</i>	Cattle, dogs, humans	<i>Hyalomma anatolicum excavatum</i> , <i>Rhipicephalus sanguineus</i>	Benisuef, Cairo, Fayoum, Giza, Qualyobia	[94,103–105]
Bovine borreliosis	<i>Borrelia theileri</i>	Cattle, horses, sheep	<i>Rhipicephalus annulatus</i>	Benisuef, Cairo, Fayoum	[45,98]
Tick-borne relapsing fever	<i>Borrelia crocidurae</i>	Foxes, hedgehogs, owls, rodents	<i>Ornithodoros erraticus</i>	Coastal strip, Lower Nile valley, Matrouh, Nile Delta	[19,106,107]
Q fever	<i>Coxiella burnetii</i>	Camels, cattle, dogs, humans	<i>Amblyomma variegatum</i> , <i>Argas persicus</i> , <i>Hyalomma anatolicum</i> , <i>Hyalomma dromedarii</i> , <i>Rhipicephalus pulchellus</i> , <i>Rhipicephalus sanguineus</i>	Alexandria, Aswan, Cairo, Dakahlia, Giza, Ismailia, Matrouh, New valley, Port Said, Sharkia, Sinai	[46,90,116–118,108–115]
Ehrlichiosis	<i>Ehrlichia canis</i>	Buffaloes, cattle, dogs, sheep	<i>Rhipicephalus sanguineus</i>	Alexandria, Cairo, Giza, Qualyobia	[81,89,119–122]
	<i>Ehrlichia minasensis</i>	Cattle	<i>Hyalomma excavatum</i> , <i>Rhipicephalus annulatus</i>	Assiut, Fayoum, New valley	[33]
	<i>Ehrlichia</i> sp.		<i>Rhipicephalus annulatus</i>	Alexandria, Aswan, Benisuef, Cairo, Dakahlia, Ismailia, Matrouh, New valley, Port Said, Sharkia, Sinai, Siwa Oasis	[75,90]
Tularemia	<i>Francisella tularensis</i>	Humans	ND	Cairo	[123]
Rickettsiosis					
Mediterranean spotted fever	<i>Rickettsia conorii</i>	Dogs, humans, rodents, sheep	ND	Aswan, Coastal strip, Nile Delta, Nile valley, Sharkia	[124–127]
African tick-borne fever	<i>Rickettsia africae</i>	Camels	<i>Hyalomma dromedarii</i> , <i>Hyalomma impeltatum</i> , <i>Hyalomma marginatum</i>	Cairo, Giza, Sinai	[128,129]
Lymphangitis-associated rickettsiosis	<i>Rickettsia sibirica mongolitimonae</i>	French traveller	ND	Red sea	[130]
	<i>Rickettsia africae</i> -like <i>Rickettsia</i> sp.	Dogs Camels	<i>Hyalomma</i> sp., <i>Rhipicephalus sanguineus</i>	Cairo Cairo, Giza, Sinai	[46] [128,131]
Alkharma hemorrhagic fever	AHFV virus	Italian tourists	ND	Shalateen	[132,133].
Crimean-Congo hemorrhagic fever	CCHF virus	Buffaloes, camels, cattle, goats, sheep	<i>Hyalomma dromedarii</i> , <i>Hyalomma excavatum</i> , <i>Hyalomma rufipes</i>	Aswan, Cairo, Sharkia	[134–140].
Lumpy skin disease	LSD virus	Cattle	<i>Rhipicephalus annulatus</i>	Benisuef	[141]
Not named	Quaranfil virus	Cattle, egrets, humans, pigeons	<i>Argas arboreus</i> , <i>Argas hermanni</i>	Qualyobia	[142]

Abbreviations: ND, Not determined; AHF, Alkharma haemorrhagic fever; CCHF, Crimean-Congo hemorrhagic fever; LSD, Lumpy skin disease.

However, severe manifestations, such as haemolytic anaemia, hepatomegaly, splenomegaly, renal failure, myocardial infarction, and death, may occur in elderly and immunocompromised patients [147,148].

In Egypt, three cases of human babesiosis have been reported. The first involved asplenic farmers who became ill, and livestock babesiosis was investigated. Serological tests revealed active infection, and the symptoms resolved with treatment [57]. The other patients had mild illnesses and recovered following treatment with atovaquone plus azithromycin or quinine and clindamycin [58,59]. Recently, five of 43 blood donor samples were seropositive for *Babesia* sp. using western blotting and immunofluorescence [60]. However, because parasite isolation or sequence analysis was not conducted on these human cases, no conclusive diagnosis was obtained, and the reservoir host for zoonotic *Babesia* sp. remained unknown.

Babesiosis causes fever, anaemia, icterus, and haemoglobinuria in animals, which may result in death. In a study conducted in 1933, two

cougars (*Puma concolor*) imported from San Francisco were housed close to other large felids at the Cairo Zoo. Three weeks later, both animals developed clinical signs of babesiosis and died. Based on the characteristic appearance of *Babesia* trophozoites, this piroplasm was named *Babesiella felis* [149]. Babesiosis has been reported in numerous governorates in Egypt. Eight *Babesia* species were detected, namely *B. bovis* in cattle, buffalo, and camel [29,30,40–42,47,150,31–33,35–39]; *B. bigemina* in cattle, buffalo, and camel [30,32,43–46,35–42]; *Babesia ovis* in sheep, goat, camel, and cattle [48,49]; *B. caballi* in horse and donkey [50,51]; *Babesia equi* in horse [52]; *B. occultans* in cattle and buffalo [33,40]; *B. canis vogeli* in dog [46,53–55]; and *Babesia behnkei* in rodents [56].

3.1.2. Theileriosis

Theileriosis is a common tick-borne protozoan disease caused by *Theileria* sp. and transmitted by ixodid ticks (*Hyalomma* sp., *Amblyomma*

Table 2

Studies reporting microscopical, serologic and/or molecular detection of tick-borne pathogens either in the ticks, animals, or humans in Egypt.

Tick-borne pathogen	No. of studies carried out in			Species molecularly confirmed by more than one study
	Ticks	Animals	Humans	
<i>Babesia</i> sp.	* [32,33,45,98] ¶ [49]	* [29,30,41–44,46,47,50–53,31, 54–56,62,72,33–37,39,40] # [38,48] ¶ [49] ‡ [61] * [62] ¶ [63,64]	# [57,58,60] ¶ [59]	<i>Babesia bigemina</i> , <i>Babesia bovis</i> , <i>Babesia caballi</i> , <i>Babesia canis vogeli</i> , <i>Babesia occultans</i>
<i>Hepatozoon</i> sp.				
<i>Theileria</i> sp.	* [33,45,46,67,75] ¶ [49]	* [36,43,70–73,75–80,46,81,82,47, 51,63,65–68] ¶ [49,83] ‡ [61]		<i>Theileria annulata</i> , <i>Theileria equi</i> , <i>Theileria lestoquardi</i> , <i>Theileria ovis</i>
<i>Anaplasma</i> sp.	* [33,46,75,89,90,95]	* [33,34,85,87,88,91,93,37,40–43,46,70,75] # [38,92] ‡ [86] * [62,98,100–102] # [96]	* [93,94]	<i>Anaplasma centrale</i> , <i>Anaplasma marginale</i> , <i>Anaplasma ovis</i> , <i>Anaplasma phagocytophilum</i> , <i>Anaplasma platys</i> , <i>Anaplasma platys</i> -like
<i>Bartonella</i> sp.				
<i>Borrelia</i> sp.	* [45,104] ¶ [19,107]	* [98,103,104] # [105] ¶ [19,106]	* [94] # [103]	<i>Borrelia burgdorferi</i> , <i>Borrelia theileri</i>
<i>Coxiella burnetii</i>	* [90,108,109]	* [46,109] ‡ [110,111,115] # [116–118]	‡ [110,115] # [116]	<i>Coxiella burnetii</i>
<i>Ehrlichia</i> sp.	* [33,89,90]	* [33,75,119,120,122] # [81,105,121]		<i>Ehrlichia canis</i>
<i>Francisella</i> sp.	* [123]	* [123]	# [123]	
<i>Rickettsia</i> sp.	* [128,129,131]	# [124–126,143]	* [130] # [127]	<i>Rickettsia africae</i>
AHF virus			* [132,133]	AHF virus
CCHF virus	* [138–140]	# [134–137]	# [135]	CCHF virus
LSD virus	* [141]			
Quaranfil virus			# [142]	

The symbol * denotes molecular detection; the symbol # denotes serologic detection; the symbol ‡ denotes studies with both serologic and molecular detection; The symbol ¶ denotes using stained blood film for detection.

Abbreviations: AHF, Alkhurma haemorrhagic fever; CCHF, Crimean-Congo hemorrhagic fever; LSD, Lumpy skin disease.

sp., *Haemaphysalis* sp., and *Rhipicephalus* sp.). Several identified *Theileria* sp. infect domestic animals and wildlife, predominantly ruminants. Some of them are pathogenic and economically relevant species, such as *Theileria parva*, which causes East Coast fever, *Theileria orientalis*, which causes *Theileria*-associated bovine anaemia, and *T. annulata*, which causes tropical theileriosis in cattle, clinically manifesting as fever, lacrimation, lymphadenopathy, and corneal opacity [71,151–153]. In contrast, other *Theileria* sp. are considered benign, such as *Theileria taurotragi*, *Theileria velifera*, and *Theileria sinensis* in cattle and *T. ovis* and *Theileria separata* in sheep and goats [151,152].

In Egypt, bovine theileriosis was first reported in 1947 in cattle and buffaloes and called Egyptian fever [154]. To date, various studies have identified different *Theileria* sp., including *T. annulata* in buffalo, cattle, camel, and sheep [36,43,71–74,46,47,65–70]; *T. ovis* in sheep, buffalo, camel, cattle, equines, and goat [46,49,66,70,72,75–77]; *T. equi* in donkey, horse, and mule [51,75,78–82]; *T. lestoquardi* in sheep and buffalo [66,72,76,77]; *Theileria uilenbergi* in buffalo [72]; *T. orientalis* in cattle and buffalo [36]; *T. separata* and *Theileria mutans* in imported camel [70]; new *Theileria africa* in equines [75]; and recently reported *Theileria haneyi* in donkey and horse from various Egyptian governorates [80].

3.1.3. Hepatozoonosis

Hepatozoonosis is a protozoan TBD in dogs. Two *Hepatozoon* species can cause hepatozoonosis: *Hepatozoon canis*, which is transmitted by *Rh. sanguineus*, and *Hepatozoon americanum*, which is transmitted by *Amblyomma maculatum* [155]. Infection mainly occurs through ingestion of vector ticks harbouring mature oocysts with infective sporozoites [156]. While *H. canis* infects haemolymphatic tissues causing pyrexia, anaemia, and lethargy, *H. americanum* infects muscular tissues, causing severe myositis and gait abnormalities [157].

In Egypt, an earlier report recorded the presence of *H. canis* in dogs heavily infested with ticks, using blood films [64]. Recently, *H. canis* was recorded in the haemolymph and midgut of *Rh. sanguineus* ticks using transmission electron microscopy [63]. Nevertheless, molecular confirmation or characterisation of *Hepatozoon* sp. has not been performed.

3.2. Bacterial diseases

3.2.1. Anaplasmosis

Anaplasmosis is a widespread tick-borne bacterial infection that affects animals and humans. Six *Anaplasma* sp. are currently recognised, including *An. marginale*, *An. centrale*, *Anaplasma bovis*, and *An. ovis* in ruminants; *An. platys* in canines; and *An. phagocytophilum* in humans and equines. The disease is known as “human granulocytic anaplasmosis” in humans and “bovine anaplasmosis” in cattle. Bovine anaplasmosis causes major economic losses because of death, abortion, reduced body condition, and decreased milk production [158].

In Egypt, *An. phagocytophilum* has been detected in sheep, human contacts, and Egyptian farmers, as well as *Rh. sanguineus* ticks attached to dogs [93–95]. Bovine anaplasmosis has been reported in numerous governorates [38,46,92]. Several studies have shown the endemicity of *An. marginale* in cattle, camel, buffalo, equines, and sheep [33,34,85–87,37,38,40–43,46,75]. *An. centrale* has been recorded in cattle and camel [37,46]. *An. ovis* has been detected in sheep, cattle, and equines [42,46,75,88], while *An. platys* has been molecularly identified in cattle, camel, dog, buffalo, *Rh. annulatus* ticks attached to cattle, and *Rh. sanguineus* ticks collected from dogs [33,40,46,89,90]. *An. platys* was reported in cattle, buffalo, sheep, and camel and isolated from *Rh. annulatus* ticks attached to equines [42,46,75].

Recently, the novel emerging species ‘*Candidatus Anaplasma camelii*’

was genetically characterised from camels imported from Sudan. However, the reservoir host, pathogenicity to camels, and zoonotic potential remain unknown [70]. These reports infer that different *Anaplasma* sp. circulate among various animal hosts and governorates in Egypt.

3.2.2. Aegyptianellosis

Aegyptianellosis is a TBD in birds, reptiles, and amphibians caused by *Aegyptianella pullorum* and transmitted to fowls by the soft tick *Ar. persicus* [159]. *Aegyptianella pullorum* has been added to the genus *Anaplasma* (family Anaplasmataceae) based on previous genetic analyses of 16S rRNA, *groESL*, and surface protein genes [160]. The main clinical signs of aegyptianellosis are ascites, severe anaemia, heart failure, and death [161]. In Egypt, an earlier report described this bacterium in the blood smears of domestic fowls that induced intraerythrocytic inclusions [162]. Subsequently, an outbreak of aegyptianellosis was reported in native Fayoumi chickens [84]. *Aegyptianella pullorum* has been isolated from argasid ticks [163].

3.2.3. Ehrlichiosis

Ehrlichiosis is a tick-borne bacterial disease detected in humans and animals worldwide. The genus *Ehrlichia* comprises five well-described species: *Ehrlichia chaffeensis*, *Ehrlichia ewingii*, *E. canis*, *Ehrlichia ruminantium*, and *Ehrlichia muris* [164]. In humans, this disease is called human monocytotropic ehrlichiosis and is caused by *E. ewingii*, *E. chaffeensis*, and *An. phagocytophilum*. In dogs, this disease is called “canine monocytotropic ehrlichiosis” and is caused by *E. canis* and *An. phagocytophilum*. Ehrlichiosis is transmitted by ixodid ticks, particularly *Rh. sanguineus* [165]. Canine ehrlichiosis has three forms: subclinical, acute, and chronic. Acute canine ehrlichiosis manifests as fever, anorexia, dyspnoea, and lymphadenopathy, whereas chronic canine ehrlichiosis can cause epistaxis, peripheral oedema, and hypotensive shock [166].

Studies on canine ehrlichiosis in Egypt are limited. *E. canis* seropositivity was recorded in dogs using immunofluorescence and enzyme-linked immunosorbent assays (ELISA) [81,121]. Furthermore, *E. canis* was isolated from dogs and *Rh. sanguineus* ticks in Cairo and Giza using polymerase chain reaction (PCR) [89,119,120,122]. Additionally, multiple new species, including *E. chaffeensis*, *Ehrlichia ovina*, *Ehrlichia minasensis*, and *Ehrlichia rustica*, have been isolated from *Hy. excavatum* and *Rh. annulatus* collected from livestock in Alexandria, Dakahlia, Siwa, Fayoum, Assiut, and New Valley [33,75,90]. Similar pathogens have been reported in ticks and cattle originating from sub-Saharan Africa (Kenya, Gambia, and Côte d’Ivoire) [167–169]. Therefore, animal imports are likely to be the main source of the introduction and spread of these pathogens.

3.2.4. Borreliosis

3.2.4.1. Lyme disease. Lyme disease is a zoonotic TBD commonly found in North America, Europe, and Asia. It is caused by the spirochete *Bo. burgdorferi* sensu lato species complex and transmitted to humans via the bite of infected *Ixodes* ticks [5]. Clinical signs include fever, fatigue, headache, and erythema migrans, a characteristic skin lesion. Moreover, the infecting bacterium can spread to other organs, resulting in severe manifestations involving the heart, joints, or nervous system unless treated [170]. In Egypt, DNA from *Bo. burgdorferi* was detected in two farmers inhabiting the Nile Delta [94]. Additionally, *Bo. burgdorferi* was isolated from humans, dogs, cattle, and ticks (*Hy. anatolicum excavatum*, *Rh. sanguineus*) in the Fayoum and Benisuef governorates [103]. Similarly, *Bo. burgdorferi* was isolated from dogs and their attached ticks *Rh. sanguineus* in Cairo and Giza [104]. Additionally, antibodies against *Bo. burgdorferi* have been detected in pet dogs from Cairo, Giza, and Qualyobia using ELISA [105].

3.2.4.2. Bovine borreliosis. Bovine borreliosis is a tick-borne spirochete

disease caused by *Bo. theileri* and transmitted by *Rhipicephalus* sp. ticks to domestic ruminants and equids in the tropical and subtropical regions worldwide [171]. It causes mild febrile illness in cattle and, occasionally, anaemia and haemoglobinuria [172]. In Egypt, *Bo. theileri* was isolated from sheep and cattle from the Benisuef and Fayoum governorates [98] and *Rh. annulatus* attached to equines in the Cairo and Benisuef governorates [75].

3.2.4.3. Tick-borne relapsing fever. TBRF is a spirochete disease caused by *Borrelia* species. It is transmitted to humans through the bite of infected argasid ticks of the genus *Ornithodoros*, resulting in recurring fever. It is found in discrete geographical areas worldwide, including Central and South America, Mexico, the Mediterranean region, Asia, and Africa [173]. In Egypt, a large survey of *O. erraticus* ticks was performed, including most Egyptian governorates, deserts, urban and cultivated areas, nests, and burrows associated with hedgehogs, rodents, owls, foxes, toads, and lizards. Aswan, several oases, and the Sinai Peninsula were not surveyed. *Borrelia (Spirochaeta) crocidurae*, was recovered from all areas and hosts, except *Meriones* sp., toads, and lizards [19]. Similarly, *Bo. crocidurae* was isolated from rodents in the Nile Delta and Matrouh governorate [106] and *O. erraticus* ticks collected from Nile grass rats in Cairo [107]. The spirochete *Borrelia persica* was found in *O. tholozani* ticks collected from the Matrouh governorate [20].

3.2.5. Rickettsiosis

Tick-borne spotted fever rickettsioses are caused by *Rickettsia* sp. bacteria belonging to the spotted fever group. Tick-borne spotted fever rickettsioses, including Mediterranean spotted fever, Rocky Mountain spotted fever, lymphangitis-associated rickettsiosis, and African tick-borne fever, are systemic tick-borne rickettsial diseases caused by *Rickettsia conorii*, *Rickettsia rickettsii*, *Rickettsia sibirica mongolitimonae*, and *R. africae*, respectively [174]. In Egypt, earlier reports have detected antibodies against *R. conorii* in rodents, sheep, and humans in most Egyptian localities [124–126]. Similarly, in a serological survey of school children in the Sharkia governorate, antibodies against *R. conorii* were detected in 37% (137/371) of children as well as in a Czech traveller who had returned from the Red Sea Governorate [127]. *Rickettsia sibirica mongolitimonae*, was reported in a French traveller who had returned from Egypt [130]. *Rickettsia rickettsii* has been identified in *Rh. sanguineus*, *Hy. anatolicum*, *Hy. impeltatum*, and *Hy. dromedarii* ticks collected from dogs, camels, and sheep in North Sinai [131]. Recently, *R. africae* was isolated from camels [128], and both *R. africae* and *R. aeschlimannii* (an agent of spotted fever) have been identified in ixodid ticks (*Hy. dromedarii*, *Hy. impeltatum*, *Hy. marginatum marginatum*) collected from camels and cows in North Sinai using PCR [90,128,129].

Okely et al. [24] listed rickettsiales symbionts among the tick-borne pathogens detected in *Hyalomma* sp. ticks in Egypt based on a previous report [90]; however, rickettsiales symbionts are non-pathogenic microorganisms.

3.2.6. Bartonellosis

Bartonellosis is a bacterial infection caused by *Bartonella* species. Currently, 15 validated species have been implicated in human disease. Among these, cat scratch disease (CSD), a zoonotic arthropod-transmitted bacterial infection in humans, is caused by *Bartonella henselae* [175]. In humans, CSD is a self-limiting disease that is mostly asymptomatic but can cause mild symptoms, such as fever and lymphadenopathy, or even severe symptoms, such as conjunctivitis, encephalopathy, and endocarditis. Domestic cats constitute the main reservoir for this pathogen, and the cat flea is the main vector [176]. *Bartonella* sp. has been detected in *Haemaphysalis* sp., *Hyalomma* sp., and *Rhipicephalus* sp. [177]. Recent experimental investigations have shown the possibility of transstadial transmission of *Ba. henselae* by *Rh. sanguineus* [178,179]. In Egypt, antibodies against *Bartonella* sp. were detected in cats from

Cairo, with a high prevalence of 59.6% [96]. In a human study from Cairo, 14.5% of examined patients with CSD were positive for *Bartonella* sp. according to the indirect fluorescent antibody test. However, cat contact was not examined as an associated risk factor [97]. A new *Bartonella* sp. was also detected in cattle in the Fayoum and Menofia governorates [98]. The zoonotic *Bartonella elizabethae* and three novel species (*Bartonella jaculi*, *Bartonella pachyuromydis*, and *Bartonella acomydis*) were isolated from rodents imported from Egypt into Japan [100,101]. Additionally, the prevalence of *Bartonella* spp. in rodents collected from Sinai Massif was 7.2%, and two *Bartonella* spp. were phylogenetically identified: *Candidatus Bartonella fadhilae* and *Candidatus Bartonella sanae* [102]. However, the zoonotic significance of these species has yet to be elucidated.

3.2.7. Tularemia

Tularaemia is a zoonotic bacterial infection caused by the intracellular bacterium *Francisella tularensis*, which results in mild-to-severe illness. It is transmitted to humans via tick bites, particularly *Dermacentor* spp., *Ixodes* spp., and *Amblyomma* spp., or through contact with infected animals [180]. Data from archaeological findings, biblical texts, and historical texts suggest that ancient Egypt, Avaris, was hit by a deadly tularaemia epidemic around 1715 BCE [181]. Since then, a solitary study has been performed recording 9.3% seropositivity of *F. tularensis* among 75 slaughterhouse workers using IgG ELISA. In addition, a significantly higher prevalence was observed among workers with frequent exposure to tick bites. However, no seropositivity was detected in ticks or camels [123].

3.2.8. Q fever

Q fever is a bacterial zoonosis caused by *C. burnetii*. It infects humans and a wide range of animals, particularly sheep, goats, cattle, and camels, through direct contact or a tick bite [182]. Clinical forms in humans are acute (self-limited fever, hepatitis, or pneumonia) or chronic (mainly endocarditis). Infection in animals is usually subclinical; however, *Coxiella*-induced abortion may occur [183]. In Egypt, the seroprevalence of *C. burnetii* has been reported in buffalo, sheep, goat, cattle, camel and humans [116–118]. Additionally, *C. burnetii* has been identified in sheep, goat, camel, and ticks (*Hy. dromedarii*, *Hy. anatolicum anatolicum*, *Ar. persicus*, *A. variegatum*, *Rh. pulchellus*, and *Rh. sanguineus*) [46,90,108–111].

3.3. Viral diseases

3.3.1. Alkhurma haemorrhagic fever

AHF is a zoonotic tick-borne viral disease caused by the AHF virus (AHFV) of the Flavivirus family. Camels and sheep have been suggested as natural hosts for AHFV. The virus RNA was isolated from *O. savignyi* and *Hy. dromedarii* ticks in Saudi Arabia [184,185]. In humans, this disease manifests as fever, vomiting, joint pain, muscle pain, and thrombocytopenia. In severe cases, haemorrhagic manifestations and encephalitis may occur, resulting in death [185,186]. In Egypt, AHFV was molecularly identified in three Italian tourists who visited a camel market in Shalateen, Southern Egypt. One of these tourists was bitten on foot by a tick-like arthropod [132,133]. Okely et al. [24] listed AHFV among the viruses isolated from Egypt based on a previous report [187]. We examined that report and found that the authors did not successfully identify AHFV in camel ticks.

3.3.2. Crimean-Congo hemorrhagic fever

CCHF is a contagious TBD transmitted by ixodid ticks, particularly *Hyalomma* spp. It has been reported in Africa, Asia, the Balkans, and the Middle East. Cattle, sheep, and camels are amplifying hosts of the CCHF virus [188]. In Egypt, previous serological studies have detected antibodies against the CCHF virus in sheep, cattle, and camels in Cairo and Aswan. Some of these animals were imported from Sudan, Somalia, and Ethiopia [135–137]. In another study, 3.13% of 1022 examined buffalo,

cattle, sheep, and goat in the Sharkia governorate were seropositive for the CCHF virus [134]. Additionally, the CCHF virus was isolated from *Hy. dromedarii* and *Hy. excavatum* ticks collected from imported animals in Sudan and Somalia [138–140].

In the Egyptian population, the exact spread of the virus is undetermined and likely to be underestimated [189], and the only recorded human death from CCHF occurred in 1981. A virologist died after accidental mouth-pipetting of a culture of the CCHF virus isolate brought from Iraq [190].

3.3.3. Lumpy skin disease

LSD is a capripox viral disease in cattle and buffaloes that results in abortion, infertility, and damage to the hide. It is transmitted mechanically via blood-feeding arthropods, such as mosquitoes and hard ticks. *Amblyomma hebraeum*, *Rh. decoloratus*, and *Rh. appendiculatus* have been implicated in the transmission of LSD in endemic areas [191]. In Egypt, recurrent outbreaks associated with devastating economic losses among cattle have recently been reported despite the adoption of the sheep pox vaccination strategy by the Egyptian government [192]. The LSD virus was isolated from different stages of *Rh. annulatus* ticks (larvae, nymphs, and adults) collected from LSD-infected cattle in Benisuef, suggesting the transmission role of ticks in the epidemiology of LSD [141].

3.3.4. Other viral diseases

3.3.4.1. The Quaranfil virus. The Quaranfil virus (QRFV) is an arbovirus isolated from *Ar. arboreus* and *Ar. hermanni* ticks, pigeon squabs, and cattle egrets, and antibodies have been detected in children with febrile illnesses in Qalyobia, Egypt [142]. Despite serological detection of neutralising antibodies against QRFV in the human population in Egypt, the actual clinical illness and disease outcome in humans is unknown. This virus causes neurological symptoms and death in chickens, guinea pigs, and mice [193].

Two other arboviruses, Chenuda and Nyamanini, were isolated from *Ar. hermanni* and *Ar. arboreus*, respectively [142]. Additionally, Thogo, Dhori and Wanworie arboviruses were isolated from *Hy. anatolicum*, *Hy. dromedarii*, and *Hy. impeltatum* ticks collected from imported camels in Matruh and Giza [194]. These viruses are transmitted by ticks to humans and cause problems ranging from mild febrile symptoms to meningoencephalitis [195]. In livestock, infection is associated with miscarriage and economic loss [196]. However, no further studies on livestock or humans in Egypt have been conducted.

4. Discussion

Due to the expanded geographical range of tick populations worldwide, the prevalence and transmission of TBDs are increasing. Many TBDs negatively affect animal and public health [197]. This review covered tick-borne infectious diseases of parasitic, bacterial, and viral origins reported in Egypt in animals and humans. Overall, owing to the limited resources and key role of the livestock sector in the Egyptian economy, research has been focused on livestock animals, and many studies have shown the active circulation of various tick-borne pathogens among domestic animals, tick vectors, and humans. Nonetheless, human infections attributable to TBDs are limited and likely to be underestimated, highlighting the requirement of genomic surveillance of bacterial and viral TBDs in humans and tick vectors, utilising metagenomic next-generation sequencing (NGS) to identify known and novel pathogens. In view of the outdated and limited number of records documenting clinical cases, the implementation of facility-based surveillance of TBDs combined with cohort studies could be a valuable approach for the assessment of the burden of communicable diseases. Building laboratory capacity in healthcare facilities to screen pathogens of public health concern is necessary with the required equipment and training of highly skilled personnel.

Among the reviewed studies, nine performed diagnoses solely based on microscopic examination of stained blood smears, which are insensitive to carrier hosts and chronic infections [198]. Additionally, several studies used ELISA, immunofluorescence, or western blotting (Table 2). However, serological assays are likely to be associated with non-specific cross-reactions and cannot differentiate between previous and current infections, resulting in potential misidentification and inconclusive epidemiological results [199]. For example, immunofluorescence showed that 13 of 43 human blood donors were seropositive for *Babesia* infection [60]. When using western blotting to confirm seropositivity, only five of the 13 positive immunofluorescence samples were positive. Similarly, differences in the prevalence rates of babesiosis and theileriosis were noted among 158 cattle using immunofluorescence (15.82% and 20.89%) and PCR (12.66% and 24.05%) for the same samples, respectively [61]. To overcome the specificity and sensitivity limitations of serological assays, molecular methods have been employed in Egypt for the surveillance of tick-borne pathogens, including nested PCR, reverse line blot, loop-mediated isothermal amplification, DNA microarray, multiplex PCR, and real-time PCR [29,33,40,41,80,94]. Although traditional molecular methods are limited in their scalability, metagenomic NGS has recently been introduced to screen multiple known and novel pathogens simultaneously [200]. A study performed in Egyptian camels utilised NGS to detect several pathogens, including *T. annulata*, *T. ovis*, *T. separata*, and *T. mutans*-like, in addition to the prokaryotic and eukaryotic profiles [70]. Making allowance that many reviewed studies failed to identify the exact subspecies of the causative agent, such as *Borrelia*, *Bartonella*, *Babesia*, *Anaplasma*, *Rickettsia*, and *Ehrlichia* [42,46,75,83,90,91,128,131], further studies using high-throughput sequencing are required to precisely characterise and identify the virome, bacteriome, and eukaryome of tick vectors, human and animal blood, for better shaping of the epidemiological picture of tick-borne pathogens in Egypt.

Circulation of different endemic pathogens, particularly *Babesia* spp., *Theileria* spp., and *Anaplasma* spp., among various livestock animals has been observed in several reviewed studies. Considering the mixed farming system of animals in Egypt, high density of livestock, and increased frequency of contact between different animal species that may harbour different tick stages, the potential spill over of several ticks and tick-borne pathogens is likely to occur among animal species. Co-infection with multiple pathogens is frequently encountered in the Egyptian livestock, particularly cattle. For instance, in a recent study from Fayoum, Assiut, and New Valley, co-infection in cattle with *An. marginale* and *T. annulata* was detected in 34/41 (82.9%) samples, followed by triple co-infection with *An. marginale*, *B. bovis*, and *T. annulata* (4.9%), and co-infection with *B. bigemina* and *An. marginale* (2.4%) or *B. occultans* and *T. annulata* (2.4%) [33]. In addition, a previous investigation included 150 cattle from BeniSuef, Fayoum, and New Valley and reported dual infection with *B. bigemina* and *An. marginale* (9/150), *T. annulata* and *An. marginale* (10/150), or *B. bigemina* and *T. annulata* (6/150) and triple infection with *B. bigemina*, *T. annulata*, and *An. marginale* (5/150) [43]. In addition to their potential implications, co-infections may enhance disease severity, presenting a challenge for diagnostic and treatment options in the clinical form of TBDs [201,202].

In Egypt, different tick species belonging to *Amblyomma* spp., *Hyalomma* spp., and *Rhipicephalus* spp. have been collected from rodents [56,203]. Rodents are reservoirs of various zoonotic pathogens and have contributed to many pandemics, such as plague and leishmaniasis [204]. In our review, many zoonotic tick-borne pathogens were identified, including *R. conorri*, *Ba. elizabethae*, and *Bo. crocidurae*. Additionally, newly discovered tick-borne pathogens, such as *B. benkei*, *Candidatus* *Ba. fahidae*, and *Candidatus* *Ba. sanaae*, have been isolated from rodents. Despite the distribution of peridomesticated rodents in rural and urban areas (around garbage dumps, agricultural lands, and canals) in Egypt and the growing list of zoonotic pathogens that document the potential significance of rodents as a disease vector, little is known about the rodent-human and animal interface in Egypt. There is a great need to fill

this epidemiological gap of knowledge and elucidate the pathogenic potential of these newly recorded tick-borne pathogens.

Introduced species of ticks and imported animals harbour and drive the spread of pathogens that have not been previously confirmed in Egypt. Some of them are responsible for great economic losses in the animal industry, such as *B. occultans*, *T. orientalis*, *T. lestoquardi*, and 'Candidatus *An. cameli*'. Other zoonotic pathogens negatively influence public health and quality of life, such as AHFV, *R. africae*, and *R. sibirica mongolitimonae*. These pathogens were likely to have been introduced to Egypt from neighbouring countries via animal trade from sub-Saharan Africa. While TBDs in humans do not seem to contribute to the overall Egyptian zoonotic disease burden, this perception should be changed as many zoonotic pathogens have been isolated from animals, ticks, and humans in Egypt. Accordingly, comprehensive surveillance studies on circulating tick-borne pathogens in the Egyptian population and provision of molecular diagnostic tools in healthcare facilities to complement serology are required. Additionally, upscaling border inspections to stop further infiltration of animals with ticks and TBDs are essential for the success of any tick control program.

Although several studies have performed tick vector identification in Egypt based on morphological characteristics, some incorrectly identified tick species, while others failed to differentiate closely related tick species [90,108,205,206]. To overcome this limitation, DNA barcoding using nuclear and mitochondrial loci has been utilised as a useful tool for the identification of cryptic tick species or even immature stages of ticks [207]. However, overlapping interspecific distances between a species result in difficulties in DNA barcoding-based identification [208,209]. Therefore, a complete mitochondrial genome (mt genome) analysis has been introduced as a promising complementary approach for tick phylogeny, and intraspecific variation [210–212]. Considering that the published data on the mt genome of ticks in Africa are limited and no previous studies have been conducted in Egypt, studies analysing complete mt-genome sequences, coupled with morphological characteristics and nucleus sequences, are required. Such studies will enable the resolution of intraspecific tick phylogenetic relationships and provide insights into population genetics [209–211].

Arboviruses (Quaranfil, Chenua, Nyamanini, Thogoto and Dhoro) have been isolated from domestic birds, ticks, and humans in Egypt [142]. Considering the daily contact of domestic birds with households, further research on human viral infections is required. Additionally, despite the isolation of over 20 pathogenic strains of viruses from migratory birds and their ticks [7–9], the potential role of migratory birds as local or long-distance disseminators of ticks and tick-borne pathogens in Egypt during their spring or winter migration is poorly understood. This highlights the requirement of further epidemiological studies on tick infestation patterns and prevalence of tick-borne pathogens harboured by these birds and the attached ticks.

The transmission chain of tick-borne pathogens involves multiple elements, including different stages of ticks (larvae, nymphs, and adult ticks), domestic animals, wildlife, and humans. However, most epidemiological studies from Egypt have investigated only one of these elements. For instance, the zoonotic *R. africae* was isolated from ixodid ticks infesting camels and cattle in Sinai. However, cattle, and humans in the same environment were not simultaneously tested [129]. In another study, *Bo. burgdorferi* was investigated in dogs and their attached ticks, and despite their zoonotic potential, humans in the same locality were not included [103]. Considering that livestock and companion animals are part of many households in villages of rural Egypt and many of them are used for work in the field and production of meat and milk and under the framework of the One Health paradigm, comprehensive epidemiological studies on TBDs should assess all disease contributors, including the vertebrate host (animals, humans, and wildlife) and ticks in the same ecological region.

In accordance with the One Health approach, a central laboratory should be established and be financially supported by the government and contain resources for molecular diagnoses and NGS. This laboratory

should actively investigate tick-borne pathogens in the Egyptian population, livestock, and ticks and serve as an information resource. Collaboration among expert researchers from various disciplines (physicians, biologists, acarologists, veterinarians, and public health professionals) is required to develop advanced research projects for the control of ticks and TBDs. Additionally, government decisions that affect animal importation should be consistent with the epidemiological findings of these projects.

5. Study limitations

Due to the limitations in the number, content, and distribution of studies, focusing on zoonotic TBDs, we could not perform meta-analysis. Similarly, we are unable to estimate the overall crude prevalence and the burden of various zoonotic TBDs in humans. Additionally, analysis of the genetic diversity, and transmission dynamics as well as assessment of the economic impact of animal TBDs has not been conducted.

6. Conclusions

This review shows that most reports are related to livestock. Despite the circulation of zoonotic tick-borne pathogens among dogs, camels, cattle, and tick vectors, few human TBDs have been documented and are potentially limited to infer the actual communicable disease burden in humans. Therefore, raising the laboratory diagnostic capacity in healthcare facilities to support routine screening of tick-borne pathogens is urgently required to improve diagnosis and inform policy-making in disease prevention. Additionally, research should be focused on major existing gaps in our understanding of the epidemiology of TBDs in Egypt, and to overcome this limitation, the One Health approach should be urgently applied to implement studies investigating animals, ticks, and humans in a defined area, combined with innovative technologies, particularly NGS. Such technologies will enable simultaneous detection of different known and novel pathogens.

Ethical approval and consent to participate

No formal ethical approval was needed.

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CRediT authorship contribution statement

Abdelbaset Eweda Abdelbaset: Conceptualization, Formal analysis, Investigation, Data curation, Writing – original draft. **Nariaki Nonaka:** Resources, Writing – review & editing. **Ryo Nakao:** Conceptualization, Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare they have no known competing interests.

Data availability

No data was used for the research described in the article.

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