


REVIEW

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# Systematic review and meta-analysis on the global distribution, host range, and prevalence of *Trypanosoma evansi*

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## Abstract

**Background:** Surra is an animal trypanosomosis, caused by infection with *Trypanosoma evansi* and leading to severe economic loss due to mortality and morbidity. Compared to tsetse-transmitted animal trypanosomoses, little attention is given to the epidemiology and control of surra. Understanding its epidemiology is a first step in local and global efforts to control the disease. We conducted a systematic review and meta-analysis of published studies on distribution, host ranges and prevalence of *T. evansi* infection.

**Methods:** Four electronic databases were searched for publications on *T. evansi* that met our inclusion criteria for the systematic review. Subsets of publications were subjected to meta-analysis for the pooled prevalence of *T. evansi* in various hosts as determined by multiple detection methods.

**Results:** A total of 272 references published between 1906–2017 were included. *Trypanosoma evansi* was reported from 48 countries; largely confined to Africa and Asia with publications on natural *T. evansi* infections from 77% ( $n = 48$ ) of countries, contrasting with seven countries in South America, and four in Europe where *T. evansi* is not endemic but was imported with infected animals. Although surra is a notifiable disease, many countries do not report surra cases to OIE. *Trypanosoma evansi* was mainly reported from dromedary camels in Africa and the Middle East, water buffaloes, cattle, dogs and horses in East and Southeast Asia. In South America, the acute form of the disease was reported in horses and dogs. Surra was also reported in a wide range of wild animals. Some rare human cases occurred in India and Vietnam. Meta-analysis on a subset of 165 publications indicated pooled prevalence of *T. evansi* in domestic animals ranging from 14–31%, 6–28% and 2–9% using respectively antibody detection, molecular and parasitological tests, with camels as the most affected, followed by buffalo and cattle.

**Conclusions:** This study illustrates that *T. evansi* affects a wide range of domestic and wild animals in Africa, Asia and South America with highest prevalence observed in dromedary camels. For successful control of *T. evansi*, both locally and globally, the role of wild animals in the epidemiology of surra needs further investigation.

**Keywords:** Trypanosomosis, *Trypanosoma evansi*, Surra, Meta-analysis, Systematic review, Prevalence, Camel

## Background

Trypanosomes are unicellular flagellar protozoa belonging to the family of Trypanosomatidae and the genus *Trypanosoma* [1]. The genus *Trypanosoma* comprises many species causing diseases called trypanosomoses in domestic and wild animals, as well as in humans [2]. Livestock trypanosomoses, caused by *Trypanosoma*

*brucei*, *T. equiperdum* and *T. evansi* that all belong to the subgenus *Trypanozoon*, have a significant socio-economic impact, and limit animal productivity throughout the world [3]. *Trypanosoma evansi* was the first pathogenic mammalian trypanosome to be described in 1880 by Griffith Evans in the blood of Indian equines and dromedaries [4]. The species evolved from *T. brucei* by adaptation to mechanical transmission, enabling it to spread beyond the tsetse belt in Africa, causing a wasting disease of livestock commonly named “surra” in Asia and Africa, and “mal de cadeiras” in

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Brazil [4]. Among the pathogenic trypanosome species, *T. evansi* is known to infect a large diversity of mammalian hosts, including endangered wild animals. Its main difference from the other trypanosomatids is the lack of maxicircle kinetoplast DNA (kDNA). *Trypanosoma evansi* does not develop in its vector [4, 5]. It is mechanically transmitted by hematophagous flies from the genera *Stomoxys* and *Tabanus*. Its mechanical transmission depends on the survival of the parasites in the oral cavity of the vector. Consequently, the smaller the interval of vector blood-sucking between an infected and an uninfected animal, the greater the success of parasite transmission [4]. In South America, transmission can occur by the common vampire bat *Desmodus rotundus* during its blood meal, acting as both vector and host [6]. Oral transmission to carnivores when feeding on fresh infected meat or carcasses has been described as well [7, 8].

Surra and its causative agent, *T. evansi* are widely distributed throughout tropical and subtropical regions of Northern Africa, Southeast Asia, as well as Central and South America [9]. In Europe, the importation of infected dromedary camels from the Canary Islands caused outbreaks in France [10] and Spain [11]. Surra kills thousands of animals every year [12]. The course of infection ranges from an acute disease with high mortality to a chronic infection characterized by subcutaneous edema, fever, lethargy, weight loss, abortion, nasal and ocular bleeding, and stiffness of the limbs. Surra can lead to neuropathy and immune suppression coupled with anemia eventually leading to death in both domestic and wild mammals [3, 13–15]. Clinical signs of neurological disorders are reported in horses, camels, buffaloes, cattle, deer and cats infected by *T. evansi* [3]. Surra has been associated with failure in vaccination against important transboundary animal diseases such as foot and mouth disease, hemorrhagic septicemia and classical swine fever [16], which pose significant impacts on global trade in live animals and animal products. Recently, there have been reports of the zoonotic potential of *T. evansi* from India and Vietnam [17–20]. In 2009, the World Organization for Animal Health (OIE) classified surra as a notifiable multispecies animal disease [21].

Despite its economic and animal health impacts, surra has been severely neglected in terms of awareness, control interventions and research into improved control tools [22]. Although *T. evansi* has been studied over the past 100 years, the epidemiology of the disease remains hardly understood in many countries and funding agencies are blatantly ignorant on the impact of this disease on populations that depend on their domestic animals. In recent years, however, a growing number of investigations have been conducted on the prevalence of *T. evansi* infection among domestic and wild animals. To

raise awareness about surra, an exhaustive literature review on the distribution of *T. evansi* and the economic losses that it causes, is the first step to take. The objective of this systematic review and meta-analysis study was to provide a global overview of the epidemiology of surra by assessing the geographical distribution of *T. evansi*, identifying domestic and wild animals that are naturally susceptible to the disease, and estimating the pooled prevalence of *T. evansi* in various animal host species.

## Methods

The systematic review (SR) and meta-analysis (MA) were conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Additional file 1: Table S1) [23]. Inclusion and exclusion criteria were defined in terms of the relevance of the references to achieve the study objectives.

## Literature search

A systematic search was conducted to identify all publications reporting the detection of *T. evansi* infection in any host. Four electronic databases - CAB Abstracts, Library of Institute of Tropical Medicine (EDS-ITM), PubMed, and ScienceDirect were searched using the search terms “evansi OR surra” applied in the title, abstract and the keywords, where applicable. No restrictions were applied with regards to language, location and date of publication (last search was run on August 17, 2017). Additional hand search of authors’ collections of relevant peer reviewed publications were also included. All references located in the searches were entered to RefWorks, a web-based reference manager software (ProQuest, Ann Arbor, MI, USA). Duplicate references with the same information about study location, numerator, denominator, and study period were removed, and abstracts were obtained for the remaining references.

## Relevant screening, inclusion and exclusion criteria

Initially, references were screened based on their titles. Unrelated references that were retrieved due to similarity in species names, such as *Lutzomyia evansi*, *Tetranychus evansi* and *Dipetalonema evansi*, were removed. In addition, references containing the term “experimental” in their title and confirmed to be exclusively about laboratory based experimental studies were removed. However, references about field trials and all ambiguous references were retained in the database for the next screening phase. All references with a title in a language other than English were stored in a dedicated RefWorks folder “Foreign language” for further screening.

References retained after initial screening were further scanned by abstract. If the information of the abstract

was not sufficient to assess whether to include or remove a reference, the full text file of the publication was screened. Full text portable document format (PDF) files that were not freely accessible online were obtained through the library of the Institute of Tropical Medicine (ITM). Publications in Dutch, French, Portuguese, Spanish and Thai languages were handled by one of the authors (PB) and another colleague. Full text publications were screened according to the following inclusion criteria: (i) if a publication contained data on any positive diagnostic test result for *T. evansi* in any naturally infected host; (ii) if a publication contained data on incidence, prevalence, host range and distribution of *T. evansi* in any naturally infected host. References were excluded by abstract if *T. evansi* was not detected in any natural host by any diagnostic test. Full text publications were excluded for one or more of the following reasons: (i) diagnostic test not specified; (ii) sample source not described; (iii) literature review; (iv) publication reporting data published elsewhere; (v) case report based on clinical signs only; (vi) outbreak report without laboratory-based confirmation; (vii) reporting a zero prevalence in any diagnostic test; (viii) detection in horses where results are indistinguishable from *T. equiperdum* infection (dourine); (ix) publication exclusively on experimental infection. References were screened by two independent reviewers (WA and PB) with all disagreements resolved by consensus.

For the quantitative meta-analysis to estimate pooled prevalence, publications that contained relevant epidemiological information such as host species, sample size, diagnostic method and prevalence were retained. A priori defined inclusion criteria were set to include publications that provided applicable quantitative information on the epidemiology of *T. evansi*. Publications with case reports, samples collected after an outbreak of surra or from clinically sick animals, insufficient or unrepresentative sample, unclear report of sample size and prevalence reported on multiple species without stratified report of prevalence by species, were excluded from the meta-analysis. Prevalence estimation was carried out after categorization of diagnostic tests and some host species. Accordingly, diagnostic tests were combined into five categories: (i) parasitological methods include wet blood smear, stained blood smear, microhematocrit concentration, and mouse inoculation; (ii) antibody-based tests include antibody-based enzyme-linked immunosorbent assay (Ab-ELISA), card agglutination test for trypanosomiasis (CATT/*T. evansi*), complement fixation test (CFT), dipstick immunoassay (DIA), indirect fluorescence antibody test (IFAT), indirect hemagglutination (IHA), immune trypanolysis (ITL), LATEX, and reverse dot blot; (iii) antigen-based tests include antigen-based enzyme-linked immunosorbent

assay (Ag-ELISA), LATEX-monoclonal antibody (LATEX-MAB), and Suratex; (iv) molecular tests include both regular and real time polymerase chain reaction (PCR) using different primers; and (v) non-specific immunological tests include formol gel test, mercuric chloride test, Takata reaction, and thymol turbidity. Species-wise categorization merged sheep and goat into “small ruminants”, horse, donkey and mule into “equine” and all studied wild animals into “wild animals”. Since large datasets were obtained for buffalo, cattle, dromedary camel, and dog analysis was carried out without categorization for these animal species.

#### Data extraction

Reference information regarding author's name, title, and year of publication were recorded in the data extraction file. From the included publications, data were extracted on country and study area (districts, province, region), duration of sample collection, host species, number of samples analyzed, type of samples collected, diagnostic method used, number of positives and prevalence or percentage. For publications that reported only the total number of animals sampled and the prevalence, the number of positives were calculated. Similarly, prevalence values were calculated for publications that reported only the number of samples and the number of positives. Case reports with the above information except prevalence data were also included for qualitative analysis. Data were extracted from the included publications by WA and PB, and any disagreement was discussed, and resolved. All data were recorded in an Excel spreadsheet (Microsoft Corp., Redmond, Washington, USA).

#### Statistical analysis

For meta-analysis, descriptive statistics were applied to determine the total number of host species included at each level of analysis and the ranges of prevalence estimates. Random-effects meta-analyses were carried out (using the total sample size and number of positives) to estimate the prevalence of *T. evansi* in different hosts. Between-study variations were assessed using the Higgins  $I^2$  statistic to estimate the percentage of total variation in prevalence estimates across the studies attributable to heterogeneity rather than chance;  $I^2 > 50\%$  may indicate substantial heterogeneity [24]. Separate meta-analyses (subgroup analysis) were conducted on data subsets to estimate the pooled prevalence of *T. evansi* with various detection methods in different hosts stratified by country. The point estimates (with 95% confidence intervals) from separate datasets were pooled using the DerSimonian-Laird random effects method [25], with the variances of the raw proportions stabilized using the Freeman-Tukey double arcsine transformation

[26, 27]. All meta-analyses were carried out using the “metaprop\_one” routine in STATA version 15 (Stata-Corp. LLC, College Station, TX, USA).

**Results and discussion**

From the initial searches based on reference titles, 3614 (3608 from databases, 6 from hand-search) potentially relevant publications were identified (Fig. 1). After primary screening of titles and abstracts, and duplicate removal, 413 references were selected for full text search. A total of 272 relevant publications that satisfied our inclusion criteria for SR were identified, of which two were in French, eight in Portuguese, two in Spanish, two in Thai, and the remaining 258 in English. Of the 272 publications selected for qualitative analysis, 165 (representing 399 datasets) were included in the MA for prevalence estimation.

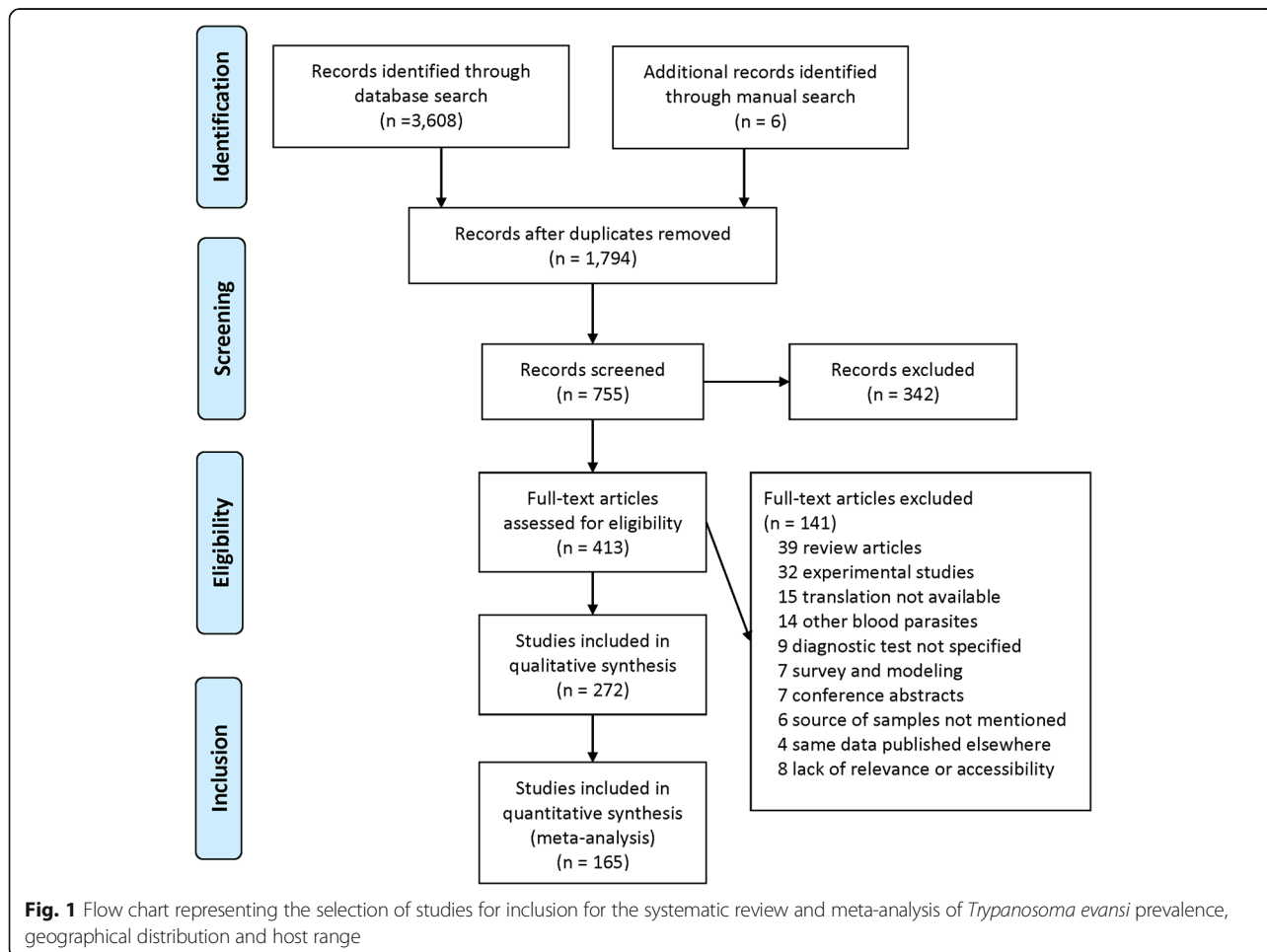
The distribution of included articles as a function of publication year is presented in Fig. 2. The oldest publication was dated from 1906. Only 29 publications were published between 1906 and 1988 with many years without any publication. Since 1990, the number of publications

on surra increased slightly and a total of 42 references were included with an average of 3.8 per year between 1989 and 1999. Since 2000, the number of publications increased considerably and 201 references were included with an average of 11.2 per year during 2000–2017. In most publications after 2000, the use of multiple diagnostic tests on diverse host species was reported.

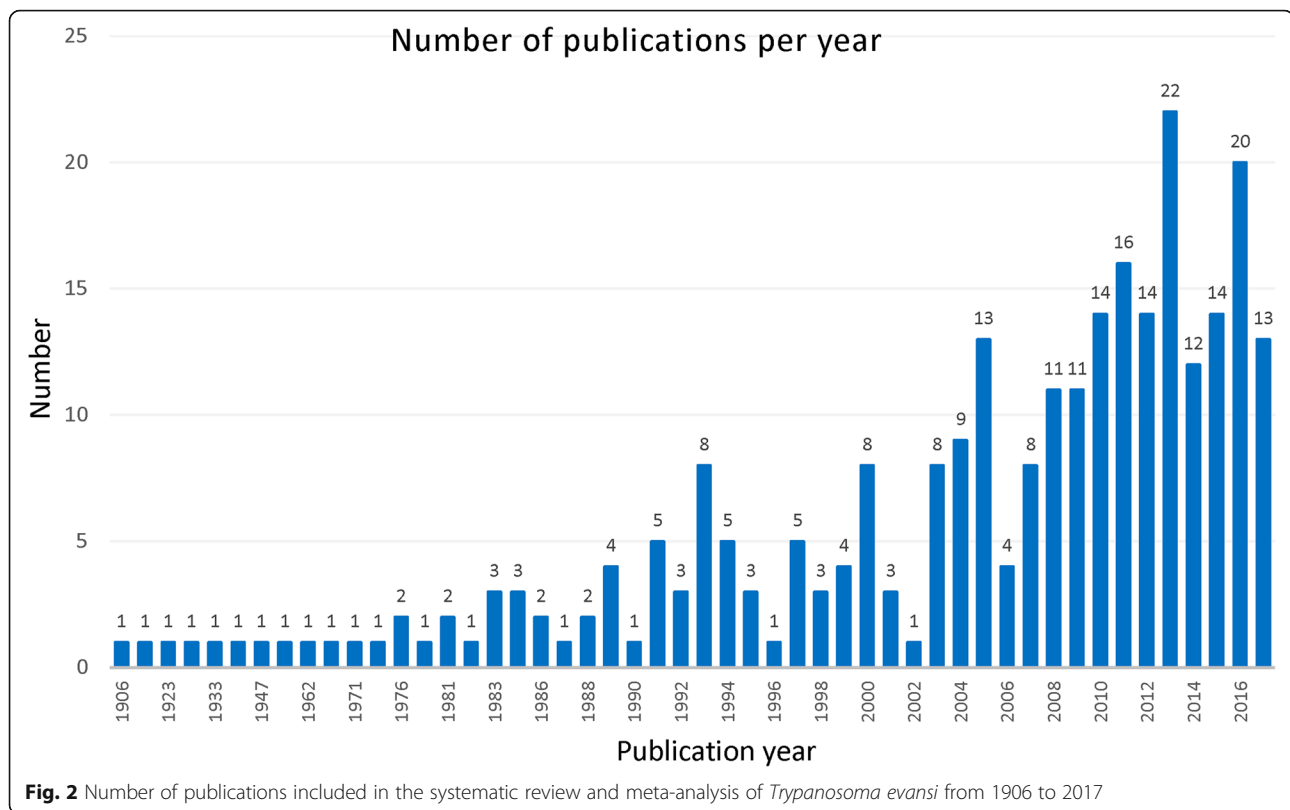
**Global distribution of surra**

Natural infections with *T. evansi* were reported from 48 countries, including 20 in Asia, 17 in Africa, seven in South America, and four in Europe (Fig. 3, Table 1). No natural infections with *T. evansi* were reported in North America, Australia and Antarctica.

Since surra became an OIE notifiable disease in 2009, 27 countries reported the presence of the disease at least once. Eight of these countries (Bangladesh, Eritrea, Myanmar, Nepal, Oman, Qatar, Togo, Uruguay) were not represented in the publications that we retrieved for this systematic review (Fig. 4). The geographical distribution of surra might not be limited to the present findings since our study included only publications with



**Fig. 1** Flow chart representing the selection of studies for inclusion for the systematic review and meta-analysis of *Trypanosoma evansi* prevalence, geographical distribution and host range

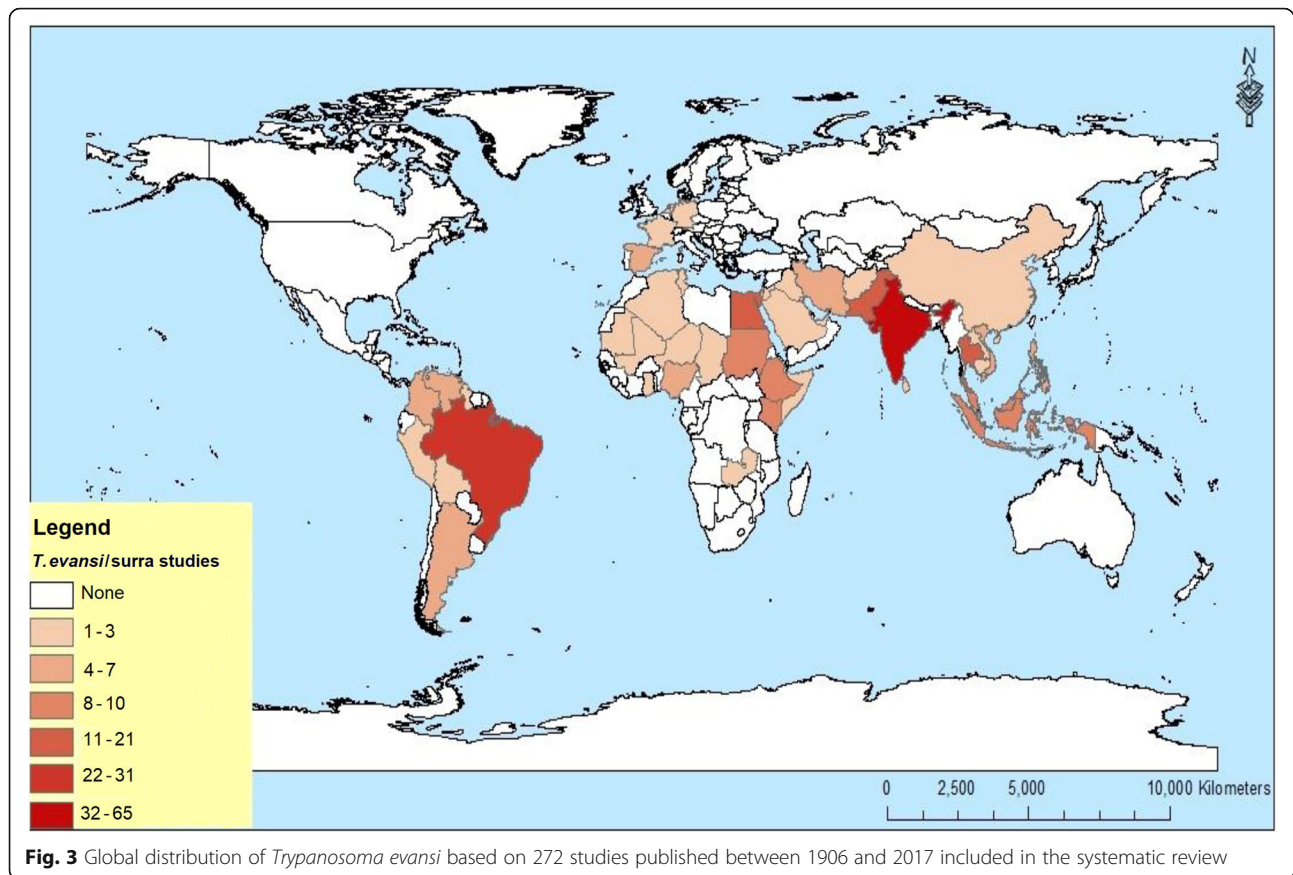


original data (excluding review articles). In addition, only natural infections of *T. evansi* with laboratory confirmations were considered. As with any systematic review, limitations associated with selection bias should be considered in this study. For example, despite several studies indicating the widespread occurrence of surra in the southern part of China as reviewed by Lun et al. [28], only one publication was included in this review probably due to language and limitations in translation. Furthermore, we only searched four globally recognized databases probably missing publications which may have been equally relevant to this study.

Surra originated in Africa where *T. evansi* evolved from *T. brucei brucei* by partial (maxicircles) or complete (mini- and maxicircles) loss of kinetoplastic DNA [5, 29]. Sixty-three publications reported *T. evansi* infections in 17 African countries (Table 1). However, the presence of *T. evansi* in Ghana and Zambia is not fully supported by the data presented in the corresponding publications [30, 31]. In these two countries, *Trypanozoon* DNA was detected by PCR (ITS1) and sequencing of the amplicons were suggestive of *T. evansi* but ITS1 sequences contain polymorphisms that are shared among all *Trypanozoon* taxa. Isolation of *T. evansi* type B which typically lacks the *RoTat 1.2* gene parasite was reported from Kenya and Ethiopia [22, 32]. According to the narrative review of Desquesnes and

co-workers [3], *T. evansi* was also reported from Libya and Burkina Faso. However, our literature search did not retrieve references for these countries.

It is generally accepted that *T. evansi* has spread from Africa into Asia through infected host species, particularly dromedary camels, horses and mules [4]. Analysis of historical data however suggests that surra was already present in India since time immemorial, at least VIII centuries B.C. [3]. The species *T. evansi* was first described as a parasite isolated from a horse in India [4, 33]. One hundred forty-eight publications described the occurrence of *T. evansi* in 20 Asian countries (Table 1). Although the majority of the retrieved publications on surra in Asia were from India, this and 10 other Asian countries did not report the disease to OIE since reporting started in 2009. Many possible explanations may exist for non-reporting of surra to the OIE, of which lack of awareness of its economic impact may be one. Another reason may be the usually chronic nature of the disease when it has become endemic. Also, we cannot exclude that countries refrain from reporting by fear of the consequences for trade of livestock and livestock products. The narrative review of Desquesnes et al. [3] mentions surra in Bhutan, Kazakhstan, Mongolia, Russia and Syria but our literature search did not retrieve any references on these countries that also did not report to OIE.



In South America, *T. evansi* was probably introduced during the 16th century with infected horses or mules of the Spanish conquistadores [34, 35]. With a total of 52 publications, the presence of *T. evansi* was reported in seven South American countries namely, Argentina, Bolivia, Brazil, Colombia, Guyana, Peru and Venezuela. Although our literature search did not retrieve any reference, *T. evansi* was reported to occur in Panama by Jaimes-Dueñez et al. [36]. More than half (30) of the publications were from Brazil, mainly from the Pantanal and Mato Grosso do Sul regions. In Pantanal, a vast flood plain in the center of South America, *T. evansi* is enzootic, infecting both domestic and wild animal species with different infective competencies [37, 38].

Nine publications reported *T. evansi* infections in Europe, all imported from non-European endemic countries. Six were about the Canary Islands that belong to Spain, where the disease became endemic after the import of dromedary camels in 1997 [39]. It is thought to have been imported there by illegal introduction of camels from Mauritania or Morocco [3]. Despite this published evidence, *T. evansi* has not been included in the animal health conditions for international trade within the European Union and other countries, resulting in two surra outbreaks originating from Gran

Canaria. The first one occurred in metropolitan France (Aveyron) in 2006 in a camel farm, and the other occurred in metropolitan Spain (Alicante) in 2008 in a mixed camel and horse farm [10, 11]. Both outbreaks were controlled by containment and treatment of all suspected and confirmed cases and surveillance of animals that were in contact with the outbreak animals. Both outbreaks that had occurred before 2009 were reported to OIE. Recently, a new document on the assessment of *T. evansi* infection including surra was developed with the framework of European animal health regulation [40]. In Germany and the Netherlands, the disease was observed in two dogs with respectively a travel history to Brazil, Spain and Thailand, and to Nepal [41, 42]. *Trypanosoma evansi* was also suspected to occur in Turkey and in Bulgaria [3] although no references were retrieved for these countries.

In Oceania, CATT/*T. evansi* seropositive animals (cattle, pig and wallaby) were observed in the Irian Jaya, a border area of Papua New Guinea with Western Indonesia but were not confirmed by parasitological or molecular tests [43]. Nevertheless, the potential role of Timor rusa deer (*Rusa timorensis*) to spread *T. evansi* into Papua New Guinea must be considered [44]. Since European settlement, five exotic trypanosomes (*T. lewisi*,

**Table 1** Continents and countries with reported *T. evansi* infection in diverse host species and detected with diverse methods

Continent	Country	No. of studies	Host <sup>c</sup>	No. of studies per host	Detection methods	References	
Africa	Algeria	2	Camel	1	Stained blood smear	[89]	
			Horse	1	Unspecified microscopic method	[90]	
	Chad	1	Camel	1	HCT and PCR	[91]	
	Egypt	13	Buffalo	1	CATT	[82]	
			Camel	10	Stained blood smear, mouse inoculation, CATT, ELISA, Suratex, Latex, thymol turbidity, PCR	[1, 77, 92–99]	
			Cattle	2	ELISA, PCR	[100, 101]	
			Goat	1	Stained blood smear, CATT, PCR	[96]	
			Sheep	1	Stained blood smear, CATT, PCR	[96]	
			Human	1	Stained blood smear, ELISA	[77]	
			Ethiopia <sup>a</sup>	8	Camel	8	Stained blood smear, HCT, CATT, ITL, PCR
			Cattle	1	HCT, CATT, PCR	[83]	
			Donkey	1	CATT, ITL, PCR	[83]	
			Goat	1	HCT, CATT, ITL, PCR	[83]	
			Horse	1	PCR	[83]	
			Mule	1	PCR	[83]	
			Sheep	1	HCT, CATT, ITL, PCR	[83]	
	Ghana <sup>b</sup>	1	Tsetse fly	1	PCR	[30]	
	Kenya	9	Camel	9	HCT, mouse inoculation, CATT, ELISA, Suratex, Latex, IHA, PCR	[13, 109–116]	
	Mali <sup>a</sup>	2	Camel	2	Unspecified microscopic method, ELISA	[48, 117]	
	Mauritania <sup>a</sup>	2	Camel	2	Stained blood smear, CATT, IFAT	[118, 119]	
	Mauritius	1	Deer	1	Stained blood smear	[120]	
	Morocco	1	Camel	1	CATT, ELISA	[121]	
	Niger <sup>a</sup>	1	Camel	1	HCT, CATT	[122]	
	Nigeria	6	Camel	3	Stained blood smear, mouse inoculation	[123–125]	
			Cattle	2	PCR	[126, 127]	
			Horse	1	Stained blood smear	[128]	
			Somalia <sup>a</sup>	3	Camel	3	Stained blood smear, HCT, ELISA
Somaliland			1	Camel	1	CATT	[132]
Sudan <sup>a</sup>			10	Camel	10	Stained blood smear, HCT, CATT, ELISA, IFAT, PCR	[88, 133–141]
				Goat	1	ELISA	[88]
	Sheep	1		ELISA	[88]		
Tunisia <sup>a</sup>	1	Dog	1	Stained blood smear, PCR	[142]		
Zambia <sup>b</sup>	1	Tabanids	1	PCR	[31]		
Asia	Afghanistan	1	Dog	1	Stained blood smear, PCR	[143]	
	Cambodia	1	Rodents	1	CATT, PCR	[63]	
	China	1	Buffalo	1	Unspecified microscopic method	[144]	
	India	65	Buffalo	16	Stained blood smear, mouse inoculation, ELISA, Latex, PCR	[86, 145–159]	
			Camel	5	Stained blood smear, mouse inoculation, ELISA, Latex, PCR	[160–164]	
		Cattle	17	Stained blood smear, mouse inoculation, ELISA, Latex, PCR	[86, 146, 149, 151, 153–156, 158, 165–172]		

**Table 1** Continents and countries with reported *T. evansi* infection in diverse host species and detected with diverse methods (Continued)

Continent	Country	No. of studies	Host <sup>c</sup>	No. of studies per host	Detection methods	References
			Dog	13	HCT, stained blood smear, mouse inoculation, ELISA, Latex, PCR	[61, 173–184]
			Donkey	1	ELISA	[185]
			Elephant	1	Unspecified microscopic method	[186]
			Goat	1	Stained blood smear	[187]
			Horse	9	Stained blood smear, mouse inoculation, ELISA, CATT, PCR	[86, 185, 188–194]
			Human	5	Stained blood smear, mouse inoculation, CATT, PCR	[17–19, 195, 196]
			Jaguar	1	Stained blood smear	[7]
			Mule	1	ELISA	[185]
			Pig	1	Stained blood smear, mouse inoculation	[197]
			Pony	1	Stained blood smear	[198]
			Sheep	1	ELISA	[199]
			Tiger	2	Stained blood smear	[7, 200]
			Cattle and buffalo	2	Stained blood smear, ELISA	[201, 202]
			Cattle, buffalo and equine	1	Stained blood smear	[151]
			Horse and mule	1	Unspecified microscopic	[203]
			Equines	3	Stained blood smear, PCR	[151, 155, 201]
	Indonesia <sup>a</sup>	10	Buffalo	4	HCT, mouse inoculation, ELISA, CATT	[204–208]
			Cattle	8	HCT, mouse inoculation, ELISA, CATT, PCR	[204–206, 209–213]
			Horse	1	ELISA	[206]
	Iran <sup>a</sup>	6	Camel	6	Stained blood smear, PCR	[214–219]
	Iraq <sup>a</sup>	1	Cattle	1	Stained blood smear	[220]
	Israel <sup>a</sup>	1	Horse	1	CATT, reverse dot blot	[87]
	Jordan <sup>a</sup>	2	Camel	2	Stained blood smear, mouse inoculation	[85, 221]
			Horse	1	Unspecified microscopic method	[85]
	Kuwait	1	Camel	1	Stained blood smear	[222]
	Laos	2	Rodents	3	CATT, PCR	[63, 223]
	Malaysia	9	Cattle	2	HCT, stained blood smear CATT, mouse inoculation	[224, 225]
			Buffalo, cattle	1	CATT	[226]
			Deer	2	HCT, CATT	[227, 228]
			Dog	1	Stained blood smear	[229]
			Horse	3	HCT, stained blood smear, CATT, PCR	[224, 230, 231]
			Rhinoceros	1	Stained blood smear	[232]
	Pakistan <sup>a</sup>	14	Bear	2	Stained blood smear, PCR	[233, 234]
			Buffalo	2	Stained blood, PCR	[235, 236]
			Camel	5	Stained blood smear, CATT, ELISA, Suratex, PCR	[79, 237–240]
			Dog	1	Stained blood smear	[241]
			Horse	1	HCT, CATT, PCR	[84]
			Equines	3	Stained blood smear, unspecified microscopic method	[242–244]
	Palestine	1	Camel	1	Unspecified microscopic method	[245]
			Mule	1	Unspecified microscopic method	[245]



**Table 1** Continents and countries with reported *T. evansi* infection in diverse host species and detected with diverse methods (Continued)

Continent	Country	No. of studies	Host <sup>c</sup>	No. of studies per host	Detection methods	References				
South America	Philippines <sup>a</sup>	6	Buffalo	4	Mouse inoculation, LAMP, PCR	[246–249]				
			Cattle	2	PCR	[250, 251]				
	Saudi Arabia	3	Camel	3	Stained blood smear, ELISA, IHA, PCR	[252–254]				
	Sri Lanka	1	Dog	1	Mouse inoculation	[255]				
	Thailand <sup>a</sup>	21	Buffalo	3	HCT, stained blood smear, mouse inoculation, ELISA and CFT	[51, 256, 257]				
			Cattle	9	HCT, stained blood smear, mouse inoculation, ELISA, IFAT, Dipstick colloidal dye immunoassay (DIA) and PCR	[50, 52, 258–264]				
			Deer (hog & rusa)	2	HCT, stained blood smear, mouse inoculation, ELISA	[265, 266]				
			Dog	1	Unspecified microscopic method	[267]				
			Elephant	1	PCR	[268]				
			Pig	1	HCT, ITL	[269]				
			Rodents	3	CATT, PCR	[63, 223, 270]				
			Horse and mule	1	HCT, stained blood smear and mouse inoculation	[53]				
			United Arab Emirates <sup>a</sup>	1	Camel	1	Stained blood smear, ELISA	[271]		
			Vietnam	4	Buffalo	3	HCT, mouse inoculation, CATT, LATEX, ELISA, ITL, PCR	[54, 272, 273]		
	Human	1			Stained blood smear, CATT, PCR	[20]				
	Argentina	4	Capybara	2	Stained blood smear, PCR	[66, 274]				
			Dog	1	Stained blood smear, PCR	[56]				
			Horse	1	Unspecified microscopic method, ELISA	[275]				
			Bolivia <sup>a</sup>	3	Cattle	3	CATT, PCR	[12, 276, 277]		
					Brazil <sup>a</sup>	30	Armadillos	1	PCR	[71]
							Bats (nectar feeding & vampire)	2	PCR	[59, 71]
Buffalo			2	PCR			[37, 71]			
Capybara			4	HCT, CATT, IFAT, ELISA, PCR			[58, 65, 71, 278]			
Cattle			3	HCT, ELISA, PCR			[37, 58, 71]			
Crab-eating fox			1	HCT, IFAT			[62]			
Coatis	5	HCT, IFAT, PCR	[71, 72, 279–281]							
Deer	2	PCR	[73, 282]							
Dog	12	HCT, stained blood smear, mouse inoculation, CATT, IFAT, ELISA, PCR	[55, 58, 62, 71, 278, 279, 283–288]							
Gray brocket	1	PCR	[73]							
Horse	12	HCT, stained blood smear, mouse inoculation, CATT, IFAT, ELISA, PCR	[38, 55, 57–59, 71, 279, 289–293]							
Ocelot	1	HCT, IFAT	[62]							
Marsupials	3	HCT, IFAT, PCR	[59, 71, 294]							
Peccaries (white-lipped & collared)	3	IFAT, PCR	[59, 70]							
Pig (feral)	2	IFAT, PCR	[59, 70]							
Crab-eating raccoon	1	PCR	[72]							
Rodents	4	HCT, IFAT, PCR	[59, 71, 74, 294]							

**Table 1** Continents and countries with reported *T. evansi* infection in diverse host species and detected with diverse methods (Continued)

Continent	Country	No. of studies	Host <sup>c</sup>	No. of studies per host	Detection methods	References	
South America	Colombia	7	Bat (vampire)	2	Stained blood smear, PCR	[68, 295]	
			Capybara	2	Stained blood smear	[64, 296]	
			Cattle	1	PCR	[297]	
			Dog	2	Stained blood smear, PCR	[36, 298]	
	Guyana	1	1	Sheep	1	IFAT	[299]
	Peru	2	Capybara	1	Unspecified microscopic method	[300]	
			Cattle	1	PCR	[12]	
	Venezuela <sup>a</sup>	5	Bat (nectar-feeding)	1	PCR	[69]	
			Capybara	3	HCT, IFAT, PCR	[301–303]	
			Cattle	2	HCT, PCR	[304]	
			Donkey	1	HCT	[302]	
			Horse	1	HCT	[302]	
	Europe	France	1	Camel	1	Unspecified microscopic method, mouse inoculation, CATT, ELISA, PCR	[10]
		Germany	1	Dog	1	Stained blood smear, CATT, PCR	[41]
The Netherlands		1	Dog	1	Unspecified microscopic method	[42]	
Spain		6	Camel	5	HCT, Stained blood smear, CATT, ELISA, PCR	[11, 305–308]	
			Cattle	1	CATT	[39]	
			Donkey	1	CATT, PCR	[11]	
			Goat	1	CATT	[39]	
			Horse	1	HCT, CATT, PCR	[11]	
Sheep	1	CATT	[39]				
Equines	1	Unspecified microscopic method, CATT	[308]				

<sup>a</sup>Reports occurrence of the disease to OIE

<sup>b</sup>Doubtful evidence obtained by non-*T. evansi* specific PCR

<sup>c</sup>Scientific names of wild animals are provided in Table 2

*T. melophagium*, *T. theileri*, *T. nabiasi* and *T. evansi*) have been identified in Australia from the various introduced mammals [45]. Fortunately, the surra-infected dromedary camels that were imported into Australia in 1907 were diagnosed quickly and *T. evansi* was eradicated from Australia before it spread [46]. Ever since, important efforts were made to prevent *T. evansi* from entering Australia and having a devastating effect on livestock and wild animals, including native marsupials that are highly susceptible to infection [43, 47].

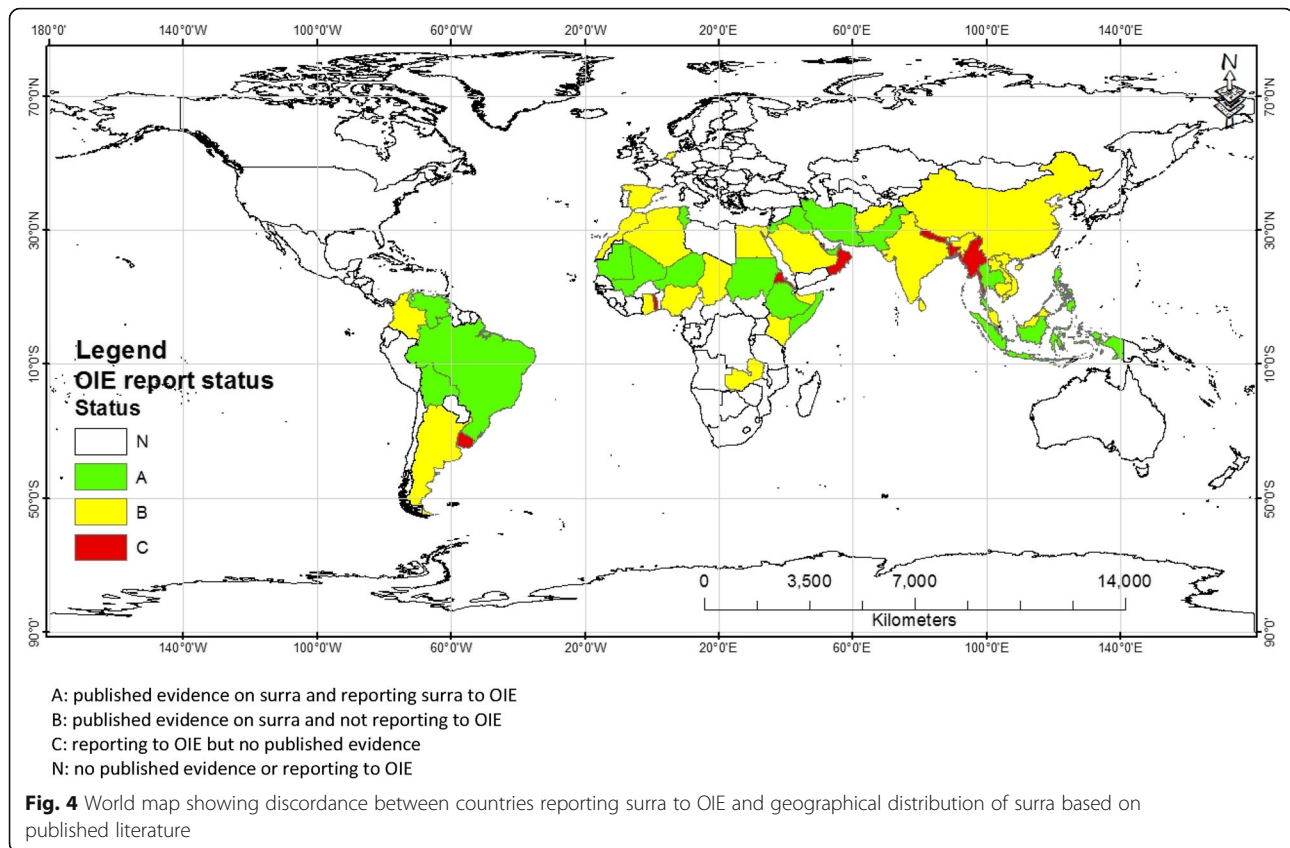
#### Host range of *T. evansi*

Our literature review confirms the very large host range of *T. evansi* that can naturally parasitise almost all domestic and many wild mammalian hosts (Table 2). *Trypanosoma evansi* was reported from dromedary camel (hereafter 'camel'), equines, cattle, goat and sheep, water

buffalo (hereafter 'buffalo'), dog and pig. Apart from the host species identified in our review, *T. evansi* has also been reported to naturally infect domestic cat, bactrian camel and llama [40].

Of the domestic animals, camel is the most studied species (83 references) followed by cattle (57), horse (37), buffalo (37), and dog (34). Similarly, camel surra appears to have the widest geographical distribution being detected in 23 countries followed by cattle, horse and dog in 16, 13 and 12 countries, respectively. The principal host species of *T. evansi* varies among the different continents.

In Africa, major outbreaks of surra were reported in camel [48, 49] which corresponds with the fact that 13 of the 17 endemic African countries reported its occurrence in camels (Table 2). Our literature review shows that camel is the only host species reported with *T.*



*evansi* infection in Chad, Kenya, Mali, Mauritania, Morocco, Niger, Somalia and Somaliland. It can therefore be concluded that among domestic animals in Africa, surra is mainly a disease of camels. In the camel, surra causes a great impairment of productivity and is considered the most economically important disease. It causes anorexia, weakness and emaciation that lead to low milk and meat yield, poor traction power, increased abortion and death [49]. Apart from camel, *T. evansi* in Africa was also reported from cattle, equine, small ruminants, dog and buffalo. Surra is generally considered a mild or negligible infection in cattle [50] although cattle, buffalo, pigs, goat and sheep that are infected with *T. evansi* suffer from immunosuppression, resulting in increased susceptibility to other diseases or in vaccination failure [16].

Also, in the Middle East camels appear to be the main affected domestic animal species. Outbreaks with clinical cases of camel trypanosomosis characterized by high mortality and abortion were reported from this region. Clinical cases, outbreaks and high prevalence of camel surra were also reported from India and Pakistan. In East and Southeast Asia, *T. evansi* mainly affects different breeds of buffaloes, cattle, dogs and horses. Apart from the high prevalence of the disease in these species, many outbreaks associated with abortion and still birth

were reported [51–54]. Asia is the first region where cattle disease caused by *T. evansi* appears to be medically and economically important [50]. The pathogenicity of *T. evansi* seems to be diverse among the Southeast Asian countries, inducing fever, weight loss, nervous symptoms and abortion.

In South America, *T. evansi* was reported in horse, cattle, buffalo, dog and sheep. It is mainly characterized by acute, progressive and severe anemia in dogs and horses [36, 55–57]. The chronic form of the disease is characterized by intermittent fever, widespread subcutaneous edema, progressive anemia, blindness, lethargy, and hemostatic alterations. In the Brazilian Pantanal, one of the most important breeding cattle centers in the country, *T. evansi* is endemic and infects various domestic and wild animals. In this region, surra in horses is called “mal de cadeiras”, characterized by anemia, immunosuppression, emaciation, severe neurological signs and death of non-treated animals. Consequently, severe economic losses occur given that horses are of pivotal importance in cattle ranching activities [57–59].

Our literature review reveals that *T. evansi* in wild animals is almost exclusively studied in Asia and South America. In Asia, many outbreaks associated with high morbidity and mortality were reported in Timor rusa deer (*Rusa timorensis*) and hog deer (*Axis porcinus*). In

**Table 2** Host range of *T. evansi* according to the 272 publications included in the systematic review

Hosts	No. of publications <sup>a</sup>	No. of countries	List of countries
Domestic animals			
Camel	83	23	Algeria, Chad, Egypt, Ethiopia, France, India, Iran, Jordan, Kenya, Kuwait, Mali, Mauritania, Morocco, Niger, Nigeria, Pakistan, Palestine, Saudi Arabia, Somalia, Somaliland, Spain, Sudan, United Arab Emirates
Cattle	57	16	Bolivia, Brazil, Colombia, Egypt, Ethiopia, India, Indonesia, Iraq, Malaysia, Papua New Guinea, Nigeria, Peru, Philippines, Spain, Thailand, Venezuela
Buffalo	37	10	Brazil, China, Egypt, India, Indonesia, Malaysia, Pakistan, Philippines, Thailand, Vietnam
Horse	37	14	Algeria, Argentina, Brazil, Ethiopia, India, Indonesia, Israel, Jordan, Malaysia, Nigeria, Pakistan, Spain, Thailand, Venezuela
Dog	34	12	Afghanistan, Argentina, Brazil, Colombia, Germany, India, Malaysia, Netherlands, Pakistan, Sri Lanka, Thailand, Tunisia
Equines	7	3	India, Pakistan, Spain
Sheep	6	6	Egypt, Ethiopia, Guyana, India, Spain, Sudan
Goat	5	5	Egypt, Ethiopia, India, Spain, Sudan
Donkey	4	4	Ethiopia, India, Spain, Venezuela
Pig	3	3	India, Thailand, Papua New Guinea
Mule	3	4	Ethiopia, India, Palestine, Thailand
Pony	1	1	India
Wild animals			
Capybara ( <i>Hydrochoerus hydrochaeris</i> )	12	5	Argentina, Brazil, Colombia, Peru, Venezuela
Rodents (Rodentia)	10	4	Brazil, Cambodia, Laos, Thailand
Deer (Cervidae)	8	4	Brazil, Malaysia, Mauritius, Thailand
Bats (Chiroptera)	5	3	Brazil, Colombia, Venezuela
Coatis ( <i>Nasua nasua</i> )	5	1	Brazil
Peccaries (Tayassuidae)	3	1	Brazil
Marsupials (Marsupialia)	3	1	Brazil
Bear ( <i>Ursus thibetanus</i> )	2	1	Pakistan
Elephant ( <i>Elephas maximus</i> )	2	2	India, Thailand
Feral pig ( <i>Sus scrofa</i> )	2	1	Brazil
Tiger ( <i>Panthera tigris</i> )	2	1	India
Armadillo (Dasypodidae)	1	1	Brazil
Crab-eating fox ( <i>Cerdocyon thous</i> )	1	1	Brazil
Jaguar ( <i>Panthera onca</i> )	1	1	India
Ocelot ( <i>Leopardus pardalis</i> )	1	1	Brazil
Crab-eating raccoon ( <i>Procyon cancrivorus</i> )	1	1	Brazil
Sumatran rhinoceros ( <i>Dicerorhinus sumatrensis</i> )	1	1	Malaysia
Agile wallaby ( <i>Macropus agilis</i> )	1	1	Papua New Guinea

<sup>a</sup>Multiple publications reported on multiple animal species

addition, clinical cases and mortality due to surra were reported in Asian or Himalayan black bear (*Ursus thibetanus*), Asian elephant (*Elephas maximus*), leopard (*Panthera pardus*), tigers (*Panthera tigris*), jaguar (*Panthera onca*) and Sumatran rhinoceros (*Dicerorhinus*

*sumatrensis*) all considered as endangered wild species in Asia [40]. Bhaskararao et al. [60] reported an outbreak of *T. evansi* in circus tigers after feeding with infected meat. The prevalence of *T. evansi* in wild ruminants and the possibility of oral transmission must be regarded as

a potential threat to wild carnivores, including endangered species [61, 62]. Various species of wild rodents in which the parasite was detected in Laos, Cambodia and Thailand, may play a reservoir role in the region [63]. Taken together, published evidence exists that *T. evansi* is a potential threat to wildlife in Asia. In South America, *T. evansi* was found in a variety of wild mammals with high prevalence values in the South American ring-tailed coatis (*Nasua nasua*) and especially in the capybara (*Hydrochoerus hydrochaeris*). *Nasua nasua* and *H. hydrochaeris* are considered as reservoirs of *T. evansi* and are regarded as sources of infection for domestic animals [64, 65]. The capybara is a large rodent found in tropical to temperate freshwater wetlands of South America [66]. This rodent species is reportedly infected with *T. evansi* in Argentina, Brazil, Colombia, Peru and Venezuela, while detection of the parasite in coatis was reported only from Brazil. Both capybara and coatis can develop similar clinical signs as seen in domestic animals; however, infected capybaras are usually asymptomatic while in coatis, clinical disease with symptoms including depression, weakness, lethargy, and some degree of anemia have been described [15, 65, 67]. Also, in South America the common vampire bat (*Desmodus rotundus*) is known to transmit *T. evansi* to other animals when taking their blood meal from them. Apart from being a vector, vampire bats can succumb to the infection and can transmit the infection among themselves, thus functioning as a reservoir [6, 68]. One publication reported on the indirect evidence of *T. evansi* in a nectar feeding bat (*Leptonycteris curasoae*), a feeding habit that precludes direct transmission of the parasite to other animals [69]. Collared peccary (*Tayassu tajacu*), white-lipped peccary (*Tayassu pecari*) and feral pigs (*Sus scrofa*) in the Pantanal region may also play a role as maintenance host for *T. evansi* due to their cryptic infections (only detectable by PCR) associated with high seroprevalence values [70]. Similarly, *T. evansi* was detected only by PCR in blood samples of armadillos (*Euphractus* spp.), gray brocket (*Mazama gouazoubira*), crab-eating raccoon (*Procyon cancrivorus*) in Brazil [71–73]. Other references report *T. evansi* detection in pampas deer (*Ozotocerus bezoarcticus*), marsh deer (*Blastocercus dichotomus*), ocelot (*Leopardus pardalis*), marsupials and rodents, the latter in the Brazilian Pantanal. Except for capybaras and vampire bats, the role of the diverse wild animal species in the epidemiology of *T. evansi* is unknown [6, 64, 66, 68, 74].

Despite the large number of publications on this topic, *T. evansi* occurring in wild animal species in Asia and South America is seldom reported to OIE. For six countries reporting to OIE the presence of *T. evansi* in wild animals (Bangladesh, Bolivia, Myanmar, Mali, Nepal, Togo) we did not retrieve any publication in our

literature search. Regarding Africa, we retrieved only one early publication on *T. evansi* in a deer in Mauritius. This reflects the poor attention that is paid to the potential role of wild animals as reservoirs of *T. evansi* in Africa, in contrast to the many studies on tsetse transmitted trypanosomes in wild animals in the continent [75, 76]. Nevertheless, wild animals may play a role on the epidemiology of *T. evansi* in Africa and in the rest of the world since under experimental conditions many wild host species are fully receptive and susceptible to *T. evansi* infection [3, 40].

Recently, three human cases with confirmed *T. evansi* infection were reported raising concerns about its zoonotic potential in endemic regions. Three publications describe infection of *T. evansi* in human patients, two from India [17, 18] and one from Vietnam [20] where diagnosis was confirmed by parasitological, molecular, and serological identification of the parasites. Also, all three cases were reported to World Health Organization (WHO) from which the drugs for treatment were obtained. The publication on a human case in Egypt [77] does not provide sufficient evidence that the patient was actually infected with *T. evansi*. Despite the wide host range of *T. evansi* in South America, human cases have not yet been reported in that continent. Compared to the closely related parasites of humans *T. brucei* (sleeping sickness) and *T. cruzi* (Chagas disease), less attention was given to possible *T. evansi* infections in humans. A recent report explains how *T. evansi* can infect humans that have a genetic or metabolic deficiency in the production of human trypanocidal apolipoprotein L1 (APOL1) that is a trypanocidal component of normal human serum [17]. The patient from Vietnam did not have APOL1 deficiency when serum was tested after treatment. A transient insufficiency in APOL1 can however not be excluded [20].

#### Prevalence of *T. evansi* in host animals and countries

A total of 165 publications (representing 399 datasets or studies) were included in the meta-analysis to estimate the prevalence of *T. evansi*. The datasets represented 152 parasitological, 114 antibody-based detection, 96 molecular, 27 antigen-based detection, and 10 non-specific immunological tests. Over one-third of the publications (143) were on camels followed by cattle (64). The characteristics of the included datasets, together with the pooled prevalence of *T. evansi* in various animal host species across all countries, stratified by detection method are presented in Table 3. Moreover, the pooled prevalence of *T. evansi* for all animal species, stratified by detection method and country are represented in Table 4.

As expected, the diagnostic method used has a major impact on reported prevalence with studies using parasitological

**Table 3** Pooled prevalence of *T. evansi* in various animal host species stratified by detection method

Host species	Detection method	No. of publications	No. of datasets	No. of animals tested	No. of animals positive	Pooled prevalence (95% CI)	Heterogeneity	
							I <sup>2</sup> (%)	P-value
Buffalo	Parasitological	14	16	10,325	474	4 (7–11)	97.8	<0.01
	Ab-based	8	10	4425	1001	28 (19–37)	97.5	<0.01
	Ag-based	3	4	3003	1612	50 (33–67)	97.6	<0.01
	Molecular	13	13	2917	379	28 (17–41)	97.7	<0.01
Camel	Parasitological	52	73	37,565	2704	9 (7–11)	97.2	<0.01
	Ab-based	25	32	24,930	7069	31 (25–37)	99.0	<0.01
	Ag-based	10	13	5102	1546	26 (19–33)	96.9	<0.01
	Molecular	10	15	6093	1582	23 (15–32)	98.2	<0.01
	NS immunoglobulin	6	10	3683	1024	35 (23–48)	98.2	<0.01
Cattle	Parasitological	18	19	13,078	253	4 (2–6)	95.6	<0.01
	Ab-based	14	15	7981	1693	19 (10–29)	99.1	<0.01
	Ag-based	6	7	1229	461	40 (20–63)	98.4	<0.01
	Molecular	22	23	6860	851	16 (10–23)	98.2	<0.01
Dog	Parasitological	8	12	8118	89	2 (1–4)	91.7	<0.01
	Ab-based <sup>a</sup>	4	5	376	78	21 (12–33)	83.3	<0.01
	Ag-based <sup>a</sup>	1	1	70	5	–	–	–
Equine	Parasitological	9	10	2772	67	2 (1–5)	91.3	<0.01
	Ab-based	11	17	7397	1123	19 (11–27)	98.5	<0.01
	Ag-based <sup>a</sup>	1	1	364	15	–	–	–
	Molecular	7	10	2190	165	6 (1–14)	97.0	<0.01
Small ruminants	Parasitological <sup>a</sup>	1	2	445	2	–	–	–
	Ab-based	5	10	3059	458	14 (5–27)	98.7	<0.01
	Molecular <sup>a</sup>	1	2	445	14	–	–	–
Wild animals	Parasitological	15	18	1426	201	15 (10–21)	88.1	<0.01
	Ab-based	10	20	2265	588	22 (13–32)	96.7	<0.01
	Molecular	15	29	2102	205	13 (8–18)	88.0	<0.01
	Ag-based <sup>a</sup>	1	1	50	11	–	–	–

**Abbreviations:** NS immunoglobulin, methods that target nonspecific immunoglobulins; CI, confidence interval; I<sup>2</sup>, between-study heterogeneity; P-value, Cochran's Q (chi-square) test of between study heterogeneity

<sup>a</sup>Estimates for subgroup categories with fewer than four datasets were omitted

methods reporting a very low prevalence in all the species compared to the other detection methods. This is due to the fact that a large proportions of infections (50–80%) in the field are chronic, and do not develop detectable levels of parasitemia [78]. Although parasitological tests are relatively cheap and fast, and are highly specific, their analytical sensitivity is rather low (parasitemia > 10<sup>2</sup> parasites/ml) except for mouse inoculation which can become positive when parasitemia is < 10 parasites/ml. However, mouse inoculation is time consuming and presents ethical concerns by the use of live animals [40]. As surrogate of parasite detection, antigen detection tests are expected to be poorly sensitive for the same reasons as parasitological tests but also due to the presence of antigen-antibody complexes [79]. Yet, in buffalo, cattle and

camel, prevalence values observed by antigen detection were higher than, or almost as high as prevalence values observed with the other tests particularly with antibody detection. A possible explanation is that the antigen detection tests are prone to non-specific reactions causing false positive results as is the case with non-specific immunoglobulin detection tests that are still routinely used for screening of surra in low-resource laboratories [79]. Non-specific immunoglobulin detection was only applied on dromedary and yielded the highest pooled prevalence (35%) (Table 3). Importantly, both the antigen detection and non-specific immunoglobulin tests are not recommended by OIE for diagnosis of surra, in contrast to parasitological, serological and molecular diagnostic methods (Chapter 2.1.17 of the OIE terrestrial manual) [80].

**Table 4** Estimated pooled prevalence values of *T. evansi* in different countries stratified by detection method and host species

Host species	Country	Diagnostic method					
		Parasitological		Ab-based		Molecular	
		No. of datasets	Prevalence (95% CI)	No. of datasets	Prevalence (95% CI)	No. of datasets	Prevalence (95% CI)
Camel	Algeria	1	14 (9–22)	–	–	–	–
	Chad	1	5 (4–6)	1	31 (29–32)	–	–
	Egypt	7	12 (5–22)	2	28 (24–32)	4	32 (8–63)
	Ethiopia	11	8 (5–13)	5	17 (8–28)	4	12 (8–18)
	India	3	8 (7–10)	–	–	–	–
	Iran	4	4 (0–11)	–	–	1	0 (0–3) <sup>a</sup>
	Jordan	3	29 (7–59)	–	–	–	–
	Kenya	10	11 (5–18)	4	51 (30–72)	1	26 (23–30)
	Kuwait	2	2 (0–4)	–	–	–	–
	Mali	2	6 (5–8)	–	–	–	–
	Mauritania	2	1 (1–2)	3	22 (15–29)	–	–
	Morocco	–	–	2	16 (15–17)	–	–
	Niger	1	12 (10–14)	1	44 (41–48)	–	–
	Nigeria	3	12 (2–29)	–	–	–	–
	Pakistan	3	4 (0–13)	3	44 (40–48)	2	31 (29–33)
	Saudi Arabia	2	4 (2–6)	2	13 (9–17)	1	25 (20–32)
	Somalia	4	4 (2–6)	1	56 (50–63)	–	–
	Somaliland	–	–	1	26 (25–28)	–	–
	Spain	2	1 (1–2)	2	6 (5–8)	–	–
	Sudan	11	9 (5–15)	4	51 (41–62)	2	40 (36–44)
United Arab Emirates	1	50 (40–60)	1	50 (40–60)	–	–	
Overall	73	9 (7–11)	32	31 (25–37)	15	23 (15–32)	
Buffalo	Brazil	–	–	–	–	2	42 (32–53)
	Egypt	–	–	1	24 (19–30)	–	–
	India	7	5 (0–12)	–	–	6	51 (27–75)
	Indonesia	4	6 (3–9)	3	54 (42–66)	–	–
	Pakistan	2	4 (3–5)	–	–	2	8 (7–9)
	Philippines	1	68 (57–78)	–	–	2	3 (1–4)]
	Thailand	1	10 (9–12)	2	17 (15–18)	–	–
	Vietnam	1	2 (1–4)	4	17 (12–24)	1	6 (3–9)
	Overall	16	7 (4–11)	10	28 (19–37)	13	28 (17–41)
Cattle	Bolivia	–	–	1	40 (36–44)	3	5 (1–12)
	Brazil	–	–	2	3 (1–4)	2	8 (6–11)
	Colombia	–	–	–	–	1	9 (7–12)
	Egypt	–	–	1	42 (37–48)	1	30 (27–35)
	Ethiopia	1	7 (5–10)	1	37 (33–42)	1	6 (4–9)
	India	9	2 (1–5)	1	2 (1–3)	7	37 (17–59)
	Indonesia	2	2 (1–2)	3	40 (31–49)	1	61 (47–74)
	Iraq	1	1 (0–4)	–	–	–	–
	Nigeria	–	–	–	–	2	0 (0–1) <sup>a</sup>
	Peru	–	–	–	–	1	3 (2–6)
	Philippines	–	–	–	–	2	1 (0–2)

**Table 4** Estimated pooled prevalence values of *T. evansi* in different countries stratified by detection method and host species (Continued)

Host species	Country	Diagnostic method						
		Parasitological		Ab-based		Molecular		
		No. of datasets	Prevalence (95% CI)	No. of datasets	Prevalence (95% CI)	No. of datasets	Prevalence (95% CI)	
	PNG	–	–	1	13 (10–18)	–	–	
	Spain	–	–	1	5 (2–9)	–	–	
	Thailand	5	6 (2–13)	4	14 (8–23)	1	30 (18–45)	
	Venezuela	1	18 (9–33)	–	–	1	26 (18–36)	
	Overall	19	4 (2–6)	15	19 (10–29)	23	16 (10–23)	
Equine	Brazil	3	3 (0–12)	6	41 (16–69)	3	12 (0–36)	
	Ethiopia	–	–	2	5 (2–9)	3	13 (1–31)	
	India	2	3 (2–6)	4	12 (9–16)	1	2 (1–5)	
	Indonesia	–	–	1	2 (1–4)	–	–	
	Israel	–	–	2	6 (5–8)	–	–	
	Jordan	1	10 (5–18)	–	–	–	–	
	Malaysia	1	1 (0–1)	1	14 (11–17)	1	1 (1–2)	
	Nigeria	2	2 (1–4)	–	–	–	–	
	Pakistan	1	1 (0–2)	1	14 (11–18)	2	1 (1–2)	
	Overall	10	2 (1–5)	17	19 (11–27)	10	6 (1–14)	
	Small ruminants	Ethiopia	–	–	4	5 (0–14)	–	–
		Guyana	–	–	1	23 (17–30)	–	–
		India	–	–	1	10 (8–13)	–	–
Spain		–	–	2	5 (4–6)	–	–	
Sudan		–	–	2	57 (52–61)	–	–	
Overall		2	–	10	14 (5–27)	2	3 (2–5)	
Dog	Brazil	4	4 (1–7)	5	21 (12–33)	–	–	
	India	7	2 (1–3)	–	–	–	–	
	Malaysia	1	0 (0–0)	–	–	–	–	
	Overall	12	2 (1–4)	5	21 (12–33)	–	–	
Wildlife	Argentina	2	11 (3–20)	–	–	1	10 (5–20)	
	Brazil	12	14 (8–22)	15	27 (19–35)	19	17 (13–20)	
	Cambodia	–	–	1	10 (7–15)	1	3 (1–8)	
	Colombia	1	24 (13–41)	–	–	1	2 (1–6)	
	Laos	–	–	1	4 (2–9)	1	3 (1–8)	
	Pakistan	1	10 (3–30)	–	–	1	25 (11–47)	
	Peru	1	28 (17–42)	–	–	–	–	
	Papua New Guinea	–	–	1	4 (1–10)	–	–	
	Thailand	–	–	1	1 (0–3)	4	1 (0–4)	
	Venezuela	1	9 (7–11)	1	50 (46–54)	1	31 (23–41)	
Overall	18	15 (10–21)	20	22 (13–32)	29	13 (8–18)		

<sup>a</sup>Zero pooled prevalence was estimated from studies with very low prevalence reports

Pooled prevalence values observed with antibody detection tests tend to be higher than with molecular tests, probably due to the fact that detectable levels of antibodies may persist for 2 to 22 months after successful trypanocidal treatment [81,

82]. On the other hand, antibody detection tests might be negative in animals that are still in the incubation period [10]. Molecular tests are considered superior to parasite and antigen detections due to their ability in detecting pre-patent and



chronic infections [79]. However, sensitivity and specificity of molecular tests vary as a function of the target sequence, primers and probes. Comparative evaluations of the various diagnostic tests for the detection of *T. evansi* are available elsewhere in the literature [40, 49, 71, 79, 80, 82–84].

Species-wise, higher estimated prevalence values were observed in camel followed by buffalo and cattle. However, the prevalence values within each species depend on the diagnostic method used and the geographical region covered by the reports, with a high heterogeneity observed among countries as a result (Tables 3 and 4). For example in camel, parasitological prevalence ranged from 1% in Spain and Mauretania to 50% in United Arab Emirates while the molecular prevalence ranged from 0% in Iran to 40% in Sudan. Similarly, parasitological prevalence in buffalo varied between 2% in Vietnam and 68% in The Philippines although these data were collected in only one publication in both countries. The overall molecular prevalence in buffalo was 28% with only 3% in The Philippines but 51% in India. In cattle the prevalence of surra was mainly studied in India and Thailand with a 2% and 6% pooled parasitological prevalence, respectively. One study in Venezuela reported an exceptionally high parasitological prevalence of 18% characteristic for an outbreak situation. Overall pooled molecular prevalence in cattle was 16% with two publications about Nigeria where the pooled prevalence was 0% to the highest pooled prevalence observed in India (37%). Horses are considered very susceptible to surra, associated with acute disease and high mortality [55, 57], while donkeys and mules are less susceptible to develop the disease [3, 53, 85]. In this study, prevalence values for equine are estimated from studies in horse, donkey and mule. Even though most of the studies were carried out in horses, the combined effect of donkey and mule seems to underestimate the prevalence of surra in horse under the equine category. Also important to note is that in some countries surra prevalence in horses, at population level is generally low, but at the farm level it can be very high within a short period of time when biting flies are abundant [86, 87]. Small ruminants might play a role as reservoir of *T. evansi*, e.g. in camel rearing areas of eastern Africa where small ruminants and camel are herded together. Yet, these animals are seldom considered which is obvious from the single publication reporting on the parasitological and molecular prevalence of surra in Ethiopian goats and sheep [83]. Reported seroprevalence values are generally low (up to 10%) except for an early study carried out in Sudan (57%). However, cross-reactions with other possibly non-pathogenic trypanosomes might have led to this higher prevalence since parasitological test revealed zero prevalence [88]. Cross-reactions or false positivity may also account for the rather high pooled seroprevalence

(21%) recorded in dogs in Brazil. Dogs might be carriers of *T. evansi* for a short period before they succumb to the infection, however they are not considered as important reservoirs but rather as epidemiological dead-end hosts that can function as sentinel hosts in a given study area [3, 40]. Investigations of *T. evansi* in wildlife were mainly carried out in South America (Brazil). Meta-analysis showed overall 15% parasitological prevalence, 22% seroprevalence and 13% molecular prevalence estimates in wildlife.

In general, this review indicated that surra is endemic in Africa, Asia and South America. In Africa, the presence of other tsetse-transmitted trypanosomes seems to overshadow surra, thus scarce information is available on surra from wildlife and humans. *Trypanosoma evansi* infects multiple mammalian species through the bite of flies, bats and carnivores, exhibiting a wide spectrum of virulence levels in different host species with multiple clinical symptoms, indicating the presence of diverse reservoirs, complex epidemiology and economic impacts.

As with any systematic review, limitations associated with potential publication bias should be considered in this meta-analysis. Statistical evaluation of publication bias was not undertaken for various reasons where variability was obviously expected within and among diagnostic test categories, geography, breed of animals sampled, period of study etc. The summary estimates derived from the meta-analyses reflect a weighted average of the records and should not be interpreted as estimates of the national prevalence of the disease.

## Conclusions

This systematic review and meta-analysis study provides comprehensive information on the geographical distribution, host range and prevalence of surra worldwide. The results confirm the wide geographical distribution and a very large host range of *T. evansi* where it can naturally parasitize almost all domestic mammals and many wild animals, and even humans. The meta-analysis showed considerable variation in estimated prevalence values as a function of diagnostic tests, host species and geography. Surra was reported from Africa, South America, Asia and Europe and not from Oceania, and North and Central America. However, many endemic countries, based on published evidence, did not report the disease to the OIE, and vice versa. In addition to the economic importance of the disease in livestock production, its detection from many endangered wild animals is an alarming situation.

## Additional file

**Additional file 1:** Table S1. PRISMA 2009 checklist. (DOCX 26 kb)

## Abbreviations

Ab: Antibody; Ag: Antigen; CATT: Card Agglutination Test for Trypanosomiasis; CFT: Complement Fixation Test; DIA: Dipstick Immunoassay; ELISA: Enzyme Linked Immunosorbent Assay; HCT: Hematocrit Centrifugation Technique; IFAT: Indirect Fluorescence Antibody Test; IHA: Indirect Hemagglutination; ITL: Immune Trypanolysis; MA: Meta-Analysis; MAB: Monoclonal Antibody; OIE: Office International des Epizooties; PCR: Polymerase Chain Reaction; SR: Systematic Review

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## Availability of data and materials

All data generated or analyzed during this study are included in this manuscript and its additional file.

## Authors' contributions

WGA and PB conceived the study. WGA, PB, GEA and RDA designed the study. WGA and PB conducted the literature search. GEA and WGA analyzed the data. WGA and GEA wrote the manuscript. All authors read and approved the final manuscript.

## Ethics approval and consent to participate

Not applicable.

## Consent for publication

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## Competing interests

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## References

- Sobhy HM, Barghash SM, Behour TS, Razin EA. Seasonal fluctuation of trypanosomiasis in camels in North-West Egypt and effect of age, sex, location, health status and vector abundance on the prevalence. *Beni-Suef Univ J Basic Appl Sci*. 2017;6:64–8.
- Mekata H, Konnai S, Mingala CN, Abes NS, Gutierrez CA, Dargantes AP, et al. Isolation, cloning, and pathologic analysis of *Trypanosoma evansi* field isolates. *Parasitol Res*. 2013;112:1513–21.
- Desquesnes M, Holzmüller P, Lai DH, Dargantes A, Lun ZR, Jittapong S. *Trypanosoma evansi* and surra: a review and perspectives on origin, history, distribution, taxonomy, morphology, hosts, and pathogenic effects. *Biomed Res Int*. 2013;2013:194176.
- Hoare CA. *The Trypanosomes of Mammals*. A Zoological Monograph. Oxford: Blackwell Scientific Publications; 1972.
- Lun ZR, Desser SS. Is the broad range of hosts and geographical distribution of *Trypanosoma evansi* attributable to the loss of maxicircle kinetoplast DNA? *Parasitol Today*. 1995;11:131–3.
- Hoare CA. Vampire bats as vectors and hosts of equine and bovine trypanosomes. *Acta Trop*. 1965;22:204–16.
- Sinha PK, Mukherjee GS, Das MS, Lahiri RK. Outbreak of *Trypanosomiasis evansi* amongst tigers and jaguars in the zoological garden, Calcutta. *Indian Vet J*. 1971;48:306–10.
- Raina AK, Kumar R, Rajora VS, Sridhar Singh RP. Oral transmission of *Trypanosoma evansi* infection in dogs and mice. *Vet Parasitol*. 1985;18:67–9.
- Sánchez E, Perrone T, Recchimuzzi G, Cardozo I, Biteau N, Aso PM, et al. Molecular characterization and classification of *Trypanosoma* spp. Venezuelan isolates based on microsatellite markers and kinetoplast maxicircle genes. *Parasit Vectors*. 2015;8:536.
- Desquesnes M, Bossard G, Thévenon S, Patrel D, Ravel S, Pavlovic D, et al. Development and application of an antibody-ELISA to follow up a *Trypanosoma evansi* outbreak in a dromedary camel herd in France. *Vet Parasitol*. 2009;162:214–20.
- Tamarit A, Gutierrez C, Arroyo R, Jimenez V, Zagalá G, Bosch I, et al. *Trypanosoma evansi* infection in mainland Spain. *Vet Parasitol*. 2010;167:74–6.
- Mekata H, Konnai S, Witola WH, Inoue N, Onuma M, Ohashi K. Molecular detection of trypanosomes in cattle in South America and genetic diversity of *Trypanosoma evansi* based on expression-site-associated gene 6. *Infect Genet Evol*. 2009;9:1301–5.
- Ngaira JM, Bett B, Karanja SM, Njagi ENM. Evaluation of antigen and antibody rapid detection tests for *Trypanosoma evansi* infection in camels in Kenya. *Vet Parasitol*. 2003;114:131–41.
- Rodrigues A, Figuera RA, Souza TM, Schild AL, Barros CS. Neuropathology of naturally occurring *Trypanosoma evansi* infection of horses. *Vet Pathol*. 2009;46:251–8.
- Santos FM, Carvalho de Macedo G, Barreto WTG, Oliveira-Santos LGR, Garcia CM, de Miranda Mourão G, et al. Outcomes of *Trypanosoma cruzi* and *Trypanosoma evansi* infections on health of southern coati (*Nasua nasua*), crab-eating fox (*Cerdocyon thous*), and ocelot (*Leopardus pardalis*) in the Brazilian Pantanal. *PLoS One*. 2018;13:e0201357.
- Payne RC, Sukanto IP, Bazeley K, Jones TW. The effect of *Trypanosoma evansi* infection on the oestrous cycle of Friesian Holstein heifers. *Vet Parasitol*. 1993;51:1–11.
- Joshi PP, Shegokar VR, Powar RM, Herder S, Katti R, Salkar HR, et al. Human trypanosomiasis caused by *Trypanosoma evansi* in India: the first case report. *Am J Trop Med Hyg*. 2005;73:491–5.
- Powar RM, Shegokar VR, Joshi PP, Dani VS, Tankhiwale NS, Truc P, et al. A rare case of human trypanosomiasis caused by *Trypanosoma evansi*. *Indian J Med Microbiol*. 2006;24:72–4.
- Dakshinkar NP, Powar RM, Shegokar VR, Dani VS, Kolte SW, Khan WA. Aberrant trypanosomiasis in human. *R Vet J India*. 2007;3:6–7.
- Van Chau VN, Le BC, Desquesnes M, Herder S, Phu HLN, Campbell JI, et al. A clinical and epidemiological investigation of the first reported human infection with the zoonotic parasite *Trypanosoma evansi* in Southeast Asia. *Clin Infect Dis*. 2016;62:1002–8.
- OIE (World Organization for Animal Health). OIE-Listed diseases, infections and infestations in force in 2018. 2018. <http://www.oie.int/animal-health-in-the-world/oie-listed-diseases-2018/>. Accessed 17 May 2018.
- Birhanu H, Gebrehiwot T, Goddeeris BM, Büscher P, Reet VN. New *Trypanosoma evansi* Type B Isolates from Ethiopian dromedary camels. *PLoS Negl Trop Dis*. 2016;10:e0004556.
- Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *J Clin Epidemiol*. 2009;62:1006–12.
- Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ*. 2003;327:557–60.
- DerSimonian R, Laird N. Meta-analysis in clinical trials. *Control Clin Trials*. 1986;7:177–88.
- Freeman MF, Tukey JW. Transformation related to the angular and the square root. *Ann Math Stat*. 1950;21:607–11.
- Nyaga VN, Arbyn M, Aerts M. Metaprop: a Stata command to perform meta-analysis of binomial data. *Arch Public Heal*. 2014;72:1–10.

28. Lun ZR, Fang Y, Wang CJ, Brun R. Trypanosomiasis of domestic animals in China. *Parasitol Today*. 1993;9:41–5.
29. Lai DH, Hashimi H, Lun ZR, Ayala FJ, Lukes J. Adaptations of *Trypanosoma brucei* to gradual loss of kinetoplast DNA: *Trypanosoma equiperdum* and *Trypanosoma evansi* are petite mutants of *T. brucei*. *Proc Natl Acad Sci USA*. 2008;105:1999–2004.
30. Nakayima J, Nakao R, Alhassan A, Mahama C, Afakye K, Sugimoto C. Molecular epidemiological studies on animal trypanosomiasis in Ghana. *Parasit Vectors*. 2012;5:217.
31. Taioe MO, Motloang MY, Namangala B, Chota A, Molefe NI, Musinguzi SP, et al. Characterization of tabanid flies (Diptera: Tabanidae) in South Africa and Zambia and detection of protozoan parasites they are harbouring. *Parasitology*. 2017;144:1162–78.
32. Ngaira JM, Olembo NK, Njagi ENM, Ngeranwa JN. The detection of non-RoTat 1.2 *Trypanosoma evansi*. *Exp Parasitol*. 2005;110:30–8.
33. Stephen LE. *Trypanosomiasis: A Veterinary Perspective*. Elmsford: Pergamon Press; 1986.
34. Luckins AG. *Trypanosoma evansi* in Asia. *Parasitol Today*. 1988;4:137–42.
35. Santos SA, Sereno JRB, Mazza MCM, Mazza CA. Origin of the Pantaneiro horse in Brazil. *Arch Zootec*. 1992;41:371–81.
36. Jaimes-Dueñez J, Triana-Chávez O, Valencia-Hernández A, Sánchez-Arévalo D, Poche-Ceballos A, Ortiz-Álvarez J, et al. Molecular diagnosis and phylogeographic analysis of *Trypanosoma evansi* in dogs (*Canis lupus familiaris*) suggest an epidemiological importance of this species in Colombia. *Prev Vet Med*. 2017;139:82–9.
37. Dávila AMR, Herrera HM, Schiebinger T, Souza SS, Traub-Cseko YM. Using PCR for unraveling the cryptic epizootiology of livestock trypanosomosis in the Pantanal, Brazil. *Vet Parasitol*. 2003;117:1–13.
38. Parreira DR, Jansen AM, Abreu UGP, Macedo GC, Silva ARS, Mazur C, et al. Health and epidemiological approaches of *Trypanosoma evansi* and equine infectious anemia virus in naturally infected horses at southern Pantanal. *Acta Trop*. 2016;163:98–102.
39. Rodríguez NF, Tejedor-Junco MT, González-Martín M, Santana del Pino A, Gutiérrez C. Cross-sectional study on prevalence of *Trypanosoma evansi* infection in domestic ruminants in an endemic area of the Canary Islands (Spain). *Prev Vet Med*. 2012;105:144–8.
40. Health EFSA Panel on Animal, More S, Bøtner A, Butterworth A, Calistri P, et al. Assessment of listing and categorisation of animal diseases within the framework of the Animal Health Law (Regulation (EU) No 2016/429): *Trypanosoma evansi* infections (including surra). *EFSA J*. 2017; 15:1–34.
41. Defontis M, Richartz J, Engelmann N, Bauer C, Schwierk VM, Büscher P, et al. Canine *Trypanosoma evansi* infection introduced into Germany. *Vet Clin Pathol*. 2012;41:369–74.
42. Hellebrekers LJ, Slappendel RJ. Trypanosomiasis in a dog imported in The Netherlands. *Vet Q*. 1982;4:182–6.
43. Reid SA, Copeman DB. Surveys in Papua New Guinea to detect the presence of *Trypanosoma evansi* infection. *Aust Vet J*. 2000;78:843–5.
44. Reid S, Husein A, Hutchinson G, Copeman D. A possible role for rusa deer (*Cervus timorensis russa*) and wild pigs in spread of *Trypanosoma evansi* from Indonesia to Papua New Guinea. *Mem Inst Oswaldo Cruz*. 1999;94:195–7.
45. Thompson CK, Godfrey SS, Thompson ARC. Trypanosomes of Australian mammals: a review. *Int J Parasitol Parasites Wildl*. 2014;3:57–66.
46. Mackerras MJ. The haematzoa of Australian mammals. *Aust J Zool*. 1959;7:105–35.
47. Reid SA. *Trypanosoma evansi* control and containment in Australasia. *Trends Parasitol*. 2002;18:219–24.
48. Dially O, Nantulya VM, Luckins AG, Diarra B, Kouyate B. Evaluation of mono- and polyclonal antibody-based antigen detection immunoassays for diagnosis of *Trypanosoma evansi* infection in the dromedary camel. *Rev Elev Med Vet Pays Trop*. 1992;45:149–53.
49. Enwezor FNC, Sackey AKB. Camel trypanosomosis - a review. *Vet Arh*. 2005; 75:439–52.
50. Desquesnes M, Kamyngkird K, Pruvot M, Kengradomkij C, Bossard G, Sarataphan N, et al. Antibody-ELISA for *Trypanosoma evansi*: application in a serological survey of dairy cattle, Thailand, and validation of a locally produced antigen. *Prev Vet Med*. 2009;90:233–41.
51. Lohr KF, Pholpark S, Siriwan P, Leesirikul N, Srikitjakarn L, Staak C. *Trypanosoma evansi* infection in buffaloes in north-east Thailand. II. Abortions. *Trop Anim Health Prod*. 1986;18:103–8.
52. Jittapalpong S, Pinyopanuwat N, Inpankaew T, Sangvaranond A, Phasuk C, Chimnoi W, et al. Prevalence of *Trypanosoma evansi* infections causing abortions among dairy cows in the central part of Thailand. *Kasetsart J (Nat Sci)*. 2009;43:53–7.
53. Tuntasuvan D, Jarabrum W, Viseshakul N, Mohkaew K, Borisutsuwan S, Theeraphan A, et al. Chemotherapy of surra in horses and mules with diminazene aceturate. *Vet Parasitol*. 2003;110:227–33.
54. Nguyen QD, Nguyen TT, Pham QP, NM LE, Nguyen GT, Inoue N. Seroprevalence of *Trypanosoma evansi* infection in water buffaloes from the mountainous region of North Vietnam and effectiveness of trypanocidal drug treatment. *J Vet Med Sci*. 2013;75:1267–9.
55. Silva RAMS, Herrera HM, da Domingos LBS, Ximenes FA, Davila AMR. Pathogenesis of *Trypanosoma evansi* infection in dogs and horses: hematological and clinical aspects. *Cienc Rural*. 1995;25:233–8.
56. Battistoni MFB, Orcellet V, Peralta JL, Marengo R, Plaza D, Brunini A, et al. First report of *Trypanosoma evansi* in a canine in Argentina. *Vet Parasitol Reg Stud Reports*. 2016;6:1–3.
57. Silva JA, Domiciano TA, Montão DP, Silva Sousa PG, Ramos LL, Argolo Paredes LJ, et al. Reemerging of natural infection by *Trypanosoma evansi* in horses in Arari Marajó Island Brazil. *Cienc Rural*. 2016;46:2170–6.
58. Franke CR, Greiner M, Mehlitz D. Investigations on naturally occurring *Trypanosoma evansi* infections in horses, cattle, dogs and capybaras (*Hydrochaeris hydrochaeris*) in Pantanal de Poconé (Mato Grosso, Brazil). *Acta Trop*. 1994;58:159–69.
59. Herrera HM, Norek A, Freitas TP, Rademaker V, Fernandes O, Jansen AM. Domestic and wild mammals infection by *Trypanosoma evansi* in a pristine area of the Brazilian Pantanal region. *Parasitol Res*. 2005;96:121–6.
60. Bhaskararao T, Raju PB, Das JH, Hafeez M. Some observations on an outbreak of surra in circus tigers. *Indian Vet J*. 1995;72:1210–21.
61. Panigrahi PN, Mahendran K, Jena SC, Behera P, Mahajan S, Arjun K, et al. *Trypanosoma evansi* infection in a German shepherd dog - apparent successful treatment using serial low dose of diminazene aceturate. *Vet Parasitol Reg Stud Reports*. 2015;1:2–70–4.
62. Herrera HM, Rocha FL, Lisboa CV, Rademaker V, Mourão GM, Ansen AM. Food web connections and the transmission cycles of *Trypanosoma cruzi* and *Trypanosoma evansi* (Kinetoplastida, Trypanosomatidae) in the Pantanal Region, Brazil. *Trans R Soc Trop Med Hyg*. 2011;105:380–7.
63. Cristina M, Kamyngkird K, Desquesnes M, Jittapalpong S, Herbretau V, Chaval Y, et al. Molecular demonstration of *Trypanosoma evansi* and *Trypanosoma lewisi* DNA in wild rodents from Cambodia, Lao PDR and Thailand. *Transbound Emerg Dis*. 2013;60:17–26.
64. Morales GA, Wells EA, Angel D. The capybara (*Hydrochoerus hydrochaeris*) as a reservoir host for *Trypanosoma evansi*. *J Wildl Dis*. 1976;12:572–4.
65. Da Silva AS, Krawczak FS, Soares JF, Klauck V, Pazinato R, Marcili A, et al. Seroprevalence of *Trypanosoma evansi* infection in capybaras (*Hydrochoerus hydrochaeris*) from a nonendemic area in Brazil. *J Vet Diagn Investig*. 2016; 28:171–4.
66. Eberhardt AT, Monje LD, Zurvera DA, Beldomenico PM. Detection of *Trypanosoma evansi* infection in wild capybaras from Argentina using smear microscopy and real-time PCR assays. *Vet Parasitol*. 2014;202:226–33.
67. Herrera HM, Aquino LPC, Menezes RF, Marques LC, Moraes MAV, Werther K, et al. *Trypanosoma evansi* experimental infection in the South American coati (*Nasua nasua*): clinical, parasitological and humoral immune response. *Vet Parasitol*. 2001;102:209–16.
68. Ayala SC, Wells EA. Disappearance of *Trypanosoma evansi* from a vampire bat colony in western Colombia. *Trans R Soc Trop Med Hyg*. 1974;68:76.
69. Silva-Iturriza A, Nassar JM, García-Rawlins AM, Rosales R, Mijares A. *Trypanosoma evansi* kDNA minicircle found in the Venezuelan nectar-feeding bat *Leptonycteris curasoae* (Glossophaginae), supports the hypothesis of multiple origins of that parasite in South America. *Parasitol Int*. 2013;62:95–9.
70. Herrera HM, Abreu UGP, Keuroghlian A, Freitas TP, Jansen AM. The role played by sympatric collared peccary (*Tayassu tajacu*), white-lipped peccary (*Tayassu pecari*), and feral pig (*Sus scrofa*) as maintenance hosts for *Trypanosoma evansi* and *Trypanosoma cruzi* in a sylvatic area of Brazil. *Parasitol Res*. 2008;103:619–24.
71. Herrera HM, Dávila AMR, Norek A, Abreu UG, Souza SS, D'Andrea PS, et al. Enzootiology of *Trypanosoma evansi* in Pantanal, Brazil. *Vet Parasitol*. 2004; 125:263–75.
72. Magalhães-Matos PC, Cunha-Santos R, Sousa PGS, Sampaio-Júnior FDS, Barros FNL, Mourão FRP, et al. Molecular detection of *Trypanosoma evansi* (Kinetoplastida: Trypanosomatidae) in procyonids (Carnivora: Procyonidae) in eastern Amazon, Brazil. *Ciência Rural*. 2016;46:663–8.

73. Silveira JAG. Occurrence of hemoparasites and ectoparasites in Mazatinga deer (*Mazama gouzoubira* Fischer, 1814), deer (*Ozotocerus bezoarticus* Linnaeus, 1758) and marsh deer (*Blastocerus dichotomus* Illiger, 1815): use of parasitological and molecular methods. PhD Thesis. Brazil: Federal University of Minas Gerais (UFMG); 2012. (In Portuguese).
74. Rademaker V, Herrera HM, Raffel TR, D'Andrea PS, Freitas TPT, Abreu UGP, et al. What is the role of small rodents in the transmission cycle of *Trypanosoma cruzi* and *Trypanosoma evansi* (Kinetoplastida: Trypanosomatidae)? A study case in the Brazilian Pantanal. *Acta Trop*. 2009;111:102–7.
75. Anderson NE, Mubanga J, Fevre EM, Picozzi K, Eisler MC, Thomas R, et al. Characterisation of the wildlife reservoir community for human and animal trypanosomiasis in the Luangwa alley, Zambia. *PLoS Negl Trop Dis*. 2011;5:e1211.
76. Auty H, Anderson NE, Picozzi K, Lembo T, Mubanga J, Hoare R, et al. Trypanosome diversity in wildlife species from the Serengeti and Luangwa Valley ecosystems. *PLoS Negl Trop Dis*. 2012;6:e1828.
77. Haridy FM, El-Metwally MT, Khalil HHM, Morsy TA. *Trypanosoma evansi* in dromedary camel: with a case report of zoonosis in Greater Cairo, Egypt. *J Egypt Soc Parasitol*. 2011;41:65–76.
78. Killick-Kendrick R. The diagnosis of trypanosomiasis of livestock; a review of current techniques. *Vet Bull*. 1968;38:191–9.
79. Tehseen S, Jahan N, Qamar MF, Desquesnes M, Shahzad MI, Deborgraeve S, et al. Parasitological, serological and molecular survey of *Trypanosoma evansi* infection in dromedary camels from Cholistan Desert, Pakistan. *Parasit Vectors*. 2015;8:413–5.
80. OIE (World Organization for Animal Health). *Trypanosoma evansi* infection (surra). OIE Terrestrial Manual 2012, Chapter. 2.1.17.; 2012. [http://www.oie.int/fileadmin/Home/eng/Health\\_standards/tahm/2.01.21\\_TRYPANO\\_SURRA.pdf](http://www.oie.int/fileadmin/Home/eng/Health_standards/tahm/2.01.21_TRYPANO_SURRA.pdf).
81. Luckins AG, Mehlitz D. Evaluation of an indirect fluorescent antibody test, enzyme-linked immunosorbent assay and quantification of immunoglobulins in the diagnosis of bovine trypanosomiasis. *Trop Anim Health Prod*. 1978;10: 149–59.
82. Hilali M, Abdel-Gawad A, Nassar A, Abdel-Wahab A, Magnus E, Büscher P. Evaluation of the card agglutination test (CATT/T. *evansi*) for detection of *Trypanosoma evansi* infection in water buffaloes (*Bubalus bubalis*) in Egypt. *Vet Parasitol*. 2004;121:45–51.
83. Birhanu H, Fikru R, Said M, Kidane W, Gebrehiwot T, Hagos A, et al. Epidemiology of *Trypanosoma evansi* and *Trypanosoma vivax* in domestic animals from selected districts of Tigray and Afar regions, northern Ethiopia. *Parasit Vectors*. 2015;8:212.
84. Tehseen S, Jahan N, Desquesnes M, Shahzad MI, Qamar MF. Field investigation of *Trypanosoma evansi* and comparative analysis of diagnostic tests in horses from Bahawalpur, Pakistan. *Turk J Vet Anim Sci*. 2017;41:288–93.
85. Abo-Shehada MN, Anshassi H, Mustafa G, Amr Z. Prevalence of surra among camels and horses in Jordan. *Prev Vet Med*. 1999;38:289–93.
86. Laha R, Sasmal NK. Detection of *Trypanosoma evansi* infection in clinically ill cattle, buffaloes and horses using various diagnostic tests. *Epidemiol Infect*. 2009;137:1583–5.
87. Berlin D, Nasereddin A, Azmi K, Ereqat S, Abdeen Z, Eyal O, et al. Prevalence of *Trypanosoma evansi* in horses in Israel evaluated by serology and reverse dot blot. *Res Vet Sci*. 2012;93:1225–30.
88. Bojd R, El-Amin EA, Mahmoud MM, Luckins AG. *Trypanosoma evansi* infections and antibodies in goats, sheep and camels in the Sudan. *Trop Anim Health Prod*. 1981;13:141–6.
89. Bennoune O, Adili N, Amri K, Bennecib L, Ayachi A. Trypanosomiasis of camels (*Camelus dromedarius*) in Algeria: first report. *Vet Res Forum*. 2013;4:273–5.
90. Anonymous. North-African Surra. *J Comp Pathol Ther*. 1906;19:60–2.
91. Delafosse A, Doutoum AA. Prevalence of *Trypanosoma evansi* infection and associated risk factors in camels in eastern Chad. *Vet Parasitol*. 2004;119: 155–64.
92. Mottelib AA, Hosein HI, Mourad I, El-Sherif AM, Abo-Zeid ASA. Comparative evaluation of various diagnostic techniques for *Trypanosoma evansi* in naturally infected camels. *Animals and Environment*, Volume 2: Proceedings of the XIIIth International Society for Animal Hygiene Congress on Animal Hygiene, Warsaw, Poland; 2005. p. 505–7.
93. Abdel-Rady A. Epidemiological studies (parasitological, serological and molecular techniques) of *Trypanosoma evansi* infection in camels (*Camelus dromedarius*) in Egypt. *Vet World*. 2008;1:325–8.
94. Saleh MA, Al-Salahy MB, Sanousi SA. Oxidative stress in blood of camels (*Camelus dromedaries*) naturally infected with *Trypanosoma evansi*. *Vet Parasitol*. 2009;162:192–9.
95. Amer S, Ryu O, Tada C, Fukuda Y, Inoue N, Nakai Y. Molecular identification and phylogenetic analysis of *Trypanosoma evansi* from dromedary camels (*Camelus dromedarius*) in Egypt, a pilot study. *Acta Trop*. 2011;117:39–46.
96. Ashour AA, Abou El-Naga TR, Barghash SM, Salama MS. *Trypanosoma evansi*: detection of *Trypanosoma evansi* DNA in naturally and experimentally infected animals using TBR1 & TBR2 primers. *Exp Parasitol*. 2013;134:109–14.
97. Elhaig MM, Youssef AI, El-Gayar AK. Molecular and parasitological detection of *Trypanosoma evansi* in Camels in Ismailia, Egypt. *Vet Parasitol*. 2013;198:214–8.
98. El-Bahr SM, El-Deeb WM. *Trypanosoma evansi* in naturally infected dromedary camels: lipid profile, oxidative stress parameters, acute phase proteins and proinflammatory cytokines. *Parasitology*. 2016;143:518–22.
99. Elmaleck BSA. Effect of seasonal variations on distribution of parasites in camels at Assiut locality. *J Vet Sci Technol*. 2016;7:279.
100. Elhaig MM, Selim A, Mahmoud MM, El-Gayar EK. Molecular confirmation of *Trypanosoma evansi* and *Babesia bigemina* in cattle from Lower Egypt. *Pak Vet J*. 2016;36:409–14.
101. Fereig RM, Mohamed SGA, Mahmoud HYA, AbouLaila MA, Guswanto A, Nguyen T, et al. Seroprevalence of *Babesia bovis*, *B. bigemina*, *Trypanosoma evansi*, and *Anaplasma marginale* antibodies in cattle in southern Egypt. *Ticks Tick Borne Dis*. 2017;8:125–31.
102. Pegram RG, Scott JM. The prevalence and diagnosis of *Trypanosoma evansi* infection in camels in southern Ethiopia. *Trop Anim Health Prod*. 1976;8:20–7.
103. Zeleke M, Bekele T. Effect of season on the productivity of camels (*Camelus dromedarius*) and the prevalence of their major parasites in eastern Ethiopia. *Trop Anim Health Prod*. 2001;33:321–9.
104. Hagos H, Yilikal A, Esayass T, Alemu T, Fikru R, Feseha G, et al. Parasitological and serological survey on trypanosomiasis (surra) in camels in dry and wet areas of Bale Zone, Oromyia Region, Ethiopia. *Rev Med Vet (Toulouse)*. 2009; 160:569–73.
105. Kassa T, Eguale T, Chaka H. Prevalence of camel trypanosomiasis and its vectors in Fentale District, South East Shoa Zone, Ethiopia. *Vet Arh*. 2011;81: 611–21.
106. Aregawi WG, Kassa TS, Tarekegn KD, Brehanu WT, Haile ST, Kiflewahid FZ. Parasitological and serological study of camel trypanosomiasis (surra) and associated risk factors in Gabi Rasu Zone, Afar, Ethiopia. *J Vet Med Anim Heal*. 2015;7:234–40.
107. Fikru R, Andualem Y, Getachew T, Menten J, Hasker E, Merga B, et al. Trypanosome infection in dromedary camels in eastern Ethiopia: prevalence, relative performance of diagnostic tools and host related risk factors. *Vet Parasitol*. 2015;211:175–81.
108. Olani A, Habtamu Y, Wegayehu T, Anberber M. Prevalence of camel trypanosomiasis (surra) and associated risk factors in Borena zone, southern Ethiopia. *Parasitol Res*. 2016;115:1141–7.
109. Gibson WC, Wilson AJ, Moloo SK. Characterisation of *Trypanosoma (Trypanozoon) evansi* from camels in Kenya using isoenzyme electrophoresis. *Res Vet Sci*. 1983;34:114–8.
110. Wilson AJ, Schwartz HJ, Dolan R, Olahu WM. A simple classification of different types of trypanosomiasis occurring in four camel herds in selected areas of Kenya. *Tropenmed Parasitol*. 1983;34:220–4.
111. Otsyula M, Kamar K, Mutugi M, Njogu AR. Preliminary efficacy trial of Cymelarsan, a novel trypanocide, in camels naturally infected with *Trypanosoma evansi* in Kenya. *Acta Trop*. 1992;50:271–3.
112. Olaho-Mukani W, Muniyua WK, Mutugi MW, Njogu AR. Comparison of antibody- and antigen-detection enzyme immunoassays for the diagnosis of *Trypanosoma evansi* infections in camels. *Vet Parasitol*. 1993;45:231–40.
113. Waithanji EM, Nantulya VM, Mbiuki SM. Use of antigen capture tube enzyme-linked immunosorbent assay for the diagnosis of *Trypanosoma evansi* infections in dromedary camels (*Camelus dromedarius*). *Rev Sci Tech*. 1993;12:665–72.
114. Nantulya VM. Suratex: a simple latex agglutination antigen test for diagnosis of *Trypanosoma evansi* infections (surra). *Trop Med Parasitol*. 1994;45:9–12.
115. Olaho-Mukani W, Nyang'ao JMN, Ouma JO. Use of suratex for field diagnosis of patent and non-patent *Trypanosoma evansi* infections in camels. *Br Vet J*. 1996;152:109–11.
116. Njirua ZK, Constantine CC, Ndung'u JM, Robertson I, Okaye S, Thompson RC, et al. Detection of *Trypanosoma evansi* in camels using PCR and CATT/T. *evansi* tests in Kenya. *Vet Parasitol*. 2004;124:187–99.
117. Diall O, Bocoum Z, Diarra B, Sanogo Y, Coulibaly Z, Waigalo Y. Epidemiology of trypanosomiasis caused by *T. evansi* in camels in Mali: results of parasitological and clinical survey. *Rev Elev Med Vet Pays Trop*. 1993;46:455–61.

118. Jacquet P, Dia ML, Cheikh D, Thiam A. Camel trypanosomiasis caused by *Trypanosoma evansi* (Steel, 1885) Balbiani 1888, in Islamic Republic of Mauritania: results of surveys in the Trarza region. *Rev Elev Med Vet Pays Trop.* 1994;47:59–62.
119. Dia ML, Diop C, Aminetou M, Jacquet P, Thiam A. Some factors affecting the prevalence of *Trypanosoma evansi* in camels in Mauritania. *Vet Parasitol.* 1997;72:111–20.
120. Adams ARD, Lionnet FE. An outbreak of surra among the wild deer (*Cervus unicolor var*) of Mauritius. *J Comp Pathol Ther.* 1933;46:165–7.
121. Atarhouch T, Rami M, Bendahman MN, Dakkak A. Camel trypanosomiasis in Morocco 1: results of a first epidemiological survey. *Vet Parasitol.* 2003;111:277–86.
122. Verloo D, Magnus E, Büscher P. Estimation of the sensitivity and the specificity of two diagnostic tests for *Trypanosoma evansi* in absence of a gold standard. In: International Scientific Council for Trypanosomiasis Research & Control (ISCTRC), 26<sup>th</sup> Meeting, Ouagadougou, Burkina Faso, 2001. Nairobi: Organization of African Unity (OAU) S and TRC (STRC) Publications, 121; 2003. p. 164–7.
123. Godfrey DG, Killick-Kendrick R. *Trypanosoma evansi* of camels in Nigeria: a high incidence demonstrated by the inoculation of blood into rats. *Ann Trop Med Parasitol.* 1962;56:14–9.
124. Audu PA, Abifarin OM. A survey of blood parasites of some domestic animals at Zango Abattoir Tudun-Wada, Kaduna. *Sokoto J Vet Sci.* 2001;3:28–33.
125. Ogbaje CI, Lawal IA, Ajanusi OJ. Infectivity and pathogenicity of Sokoto (Northern Nigeria) isolate of *Trypanosoma evansi* in west African dwarf goats. *Int J Anim Vet Adv.* 2011;3:117.
126. Takeet MI, Fagbemi BO, De Donato M, Yakubu A, Rodulfo HE, Peters SO, et al. Molecular survey of pathogenic trypanosomes in naturally infected Nigerian cattle. *Res Vet Sci.* 2013;94:555–61.
127. Ode S, Adamu M, Taioe M, Thekiso O, Adamu S, Saror DI. Molecular occurrence of trypanosomes, erythrocyte and serum sialic acid concentrations of Muturu and Bunaji cattle in Benue State, Nigeria. *Vet Parasitol.* 2017;242:10–3.
128. Ehizibolo DO, Kamani J, Ehizibolo PO, Egwu KO, Dogo GI, Salami-Shinaba JO. Prevalence and significance of parasites of horses in some states of northern Nigeria. *J Equine Sci.* 2012;23:1–4.
129. Hunter AG. Urine odour in a camel suffering from surra (*T. evansi* infection). *Trop Anim Health Prod.* 1986;18:146–8.
130. Dirie MF, Wallbanks KR, Aden AA, Bornstein S, Ibrahim MD. Camel trypanosomiasis and its vectors in Somalia. *Vet Parasitol.* 1989;32:285–91.
131. Baumann MP, Zessin KH. Productivity and health of camels (*Camelus dromedarius*) in Somalia: associations with trypanosomiasis and brucellosis. *Trop Anim Health Prod.* 1992;24:145–56.
132. Salah AA. Epidemiological studies on camel trypanosomiasis (surra) and its control and economic impact in Somaliland. PhD Thesis, Murdoch University, Western Australia; 2016.
133. Luckins AG, Boid R, Rae P, Mahmoud MM, el Malik KH, Gray AR. Serodiagnosis of infection with *Trypanosoma evansi* in camels in the Sudan. *Trop Anim Health Prod.* 1979;11:1–12.
134. Boid R. Isoenzyme characterisation of 15 stocks of *Trypanosoma evansi* isolated from camels in the Sudan. *Trop Med Parasitol.* 1988;39:45–50.
135. Rae PF, Thrusfield MV, Higgins A, Aitken CG, Jones TW, Luckins AG. Evaluation of enzyme immunoassays in the diagnosis of camel (*Camelus dromedarius*) trypanosomiasis: a preliminary investigation. *Epidemiol Infect.* 1989;102:297–307.
136. Hussein KS, Gasmir GS. Presence of ketones in the serum of *Trypanosoma evansi* infected camels (*Camelus dromedarius*) in the Sudan. *Rev Elev Med Vet Pays Trop.* 1993;46:578–9.
137. Elamin EA, el Bashir MO, Saeed EM. Prevalence and infection pattern of *Trypanosoma evansi* in camels in mid-eastern Sudan. *Trop Anim Health Prod.* 1998;30:107–14.
138. Ali NOM, Croft HI, Abdalla HS. Molecular diagnosis of *Trypanosoma evansi* infection in *Camelus dromedarius* from eastern and western regions of the Sudan. *Emirates J Food Agric.* 2011;23:320–9.
139. Salim B, Bakheit MA, Kamau J, Nakamura I, Sugimoto C. Molecular epidemiology of camel trypanosomiasis based on ITS1 rDNA and RoTat 1.2 VSG gene in the Sudan. *Parasit Vectors.* 2011;4:31.
140. Babeker EA, Elrasoul YMH. Incidence and treatment of camel trypanosomiasis (Guffar) in west Omdurman in Sudan. *J Vet Adv.* 2014;4:582–93.
141. Mossaad E, Salim B, Sukanuma K, Musinguzi P, Hassan MA, Elamin EA, et al. *Trypanosoma vivax* is the second leading cause of camel trypanosomiasis in Sudan after *Trypanosoma evansi*. *Parasit Vectors.* 2017;10:176.
142. Rjeibi MR, Ben Hamida T, Dalgatova Z, Mahjoub T, Rejeb A, Dridi W, et al. First report of surra (*Trypanosoma evansi* infection) in a Tunisian dog. *Parasite.* 2015;22:3.
143. Aref M, Yasin SM, Bahear W, Ghulam Z, Hastie L, Dennison T, et al. Canine *Trypanosoma evansi* infection in Afghanistan. *Vet Parasitol.* 2013;197:638–41.
144. Lun Z-R, Min Z-P, Huang D, Liang J-X, Yang X-F, Huang Y-T. Cymelarsan in the treatment of buffaloes naturally infected with *Trypanosoma evansi* in South China. *Acta Trop.* 1991;49:233–6.
145. Sangwan N, Chaudhri SS, Rao AR, Sangwan AK, Gupta RP. Folicin and cyanocobalamin in relation to natural *Trypanosoma evansi* infection in buffaloes. *Trop Anim Health Prod.* 1993;25:79–84.
146. Singla LD, Aulakh GS, Juyal PD, Singh J. Bovine trypanosomiasis in Punjab India. Animal health: a breakpoint in economic development? The 11th International Conference of the Association of Institutions for Tropical Veterinary Medicine and 16th Veterinary Association Malaysia Congress, 23–27 August 2004, Petaling Jaya, Malaysia; 2004. p. 283–5.
147. Gangurde KC, Keskar DV, Gaikwad RV, Sonawale VB. A case report: trypanosomiasis in a buffalo of Nashik city. *J Bombay Vet Coll.* 2006;14:131.
148. Arunachalam K, Anna T, Senthilvel K, Ponnudurai G, Harikrishnan TJ. *Trypanosoma evansi* infection in a buffalo. *North-East Vet (Guwahati).* 2008;7:14.
149. Menon DG, Mathew L. Incidence of *Trypanosoma evansi* in Thrissur town. *Vet World.* 2008;1:275–7.
150. Rayulu VC, Singh A, Chaudhri SS. Monoclonal antibody based immunoassays for the detection of circulating antigens of *Trypanosoma evansi* in buffaloes. *Ital J Anim Sci.* 2010;6:907–10.
151. Kunhipurayil S, Gupta SK, Singh A, Chaudhary SS, Gupta J. Polymerase chain reaction based detection of *Trypanosoma evansi* in whole blood of domestic animals. In: Advances in Parasitology: A Novel Approach Towards a Disease Free World. Proceedings of the 22nd National Congress on Parasitology, University of Kalyani, West Bengal, India; 2011. p. 302–4.
152. Shyma KP, Gupta SK, Singh A, Chaudhri SS. Efficiency of monoclonal antibody based latex agglutination test in detecting *Trypanosoma evansi* under field conditions for improving the productivity in buffaloes. *Buffalo Bull.* 2012;31:163–72.
153. Chaudhri SS, Bisla RS, Bhanot V, Singh H. Prevalence of haemoprotozoan infections in pyretic dairy animals of eastern Haryana. *Indian J Anim Res.* 2013;47:344–7.
154. Sharma A, Das Singla L, Tuli A, Kaur P, Batth BK, Javed M, et al. Molecular prevalence of *Babesia bigemina* and *Trypanosoma evansi* in dairy animals from Punjab, India, by duplex PCR: a step forward to the detection and management of concurrent latent infections. *Biomed Res Int.* 2013;2013:893862.
155. Shyam KP, Gupta SK, Singh A, Chaudhary SS, Gupta JP. Detection of *Trypanosoma evansi* in whole blood of domestic animals by DNA amplification method. *Indian J Anim Res (Karnal).* 2013;47:456–9.
156. Sharma A, Das Singla L, Tuli A, Kaur P, Bal MS. Detection and assessment of risk factors associated with natural concurrent infection of *Trypanosoma evansi* and *Anaplasma marginale* in dairy animals by duplex PCR in eastern Punjab. *Trop Anim Health Prod.* 2015;47:251–7.
157. Ponnudurai G, Sivaraman S, Rani N, Veerapandian C. An outbreak of trypanosomiasis in buffaloes caused by diminazene resistant *Trypanosoma evansi*. *Buffalo Bull.* 2015;34:1–4.
158. Murthy CMK, Ananda KJ, Adeppa J. Prevalence of haemoprotozoan infections in bovines of Shimoga region of Karnataka State. *J Parasit Dis.* 2016;40:890–2.
159. Migri S, Bharkad GP, Gatne ML. Prevalence of clinical and subclinical forms of *Trypanosoma evansi* infection in buffaloes of Mumbai region (MS) of India. *Buffalo Bull.* 2016;35:679–85.
160. Pathak KML, Arora JK, Kapoor M. Camel trypanosomiasis in Rajasthan, India. *Vet Parasitol.* 1993;49:319–23.
161. Pathak KML, Singh Y, Meirvenne NV, Kapoor M. Evaluation of various diagnostic techniques for *Trypanosoma evansi* infections in naturally infected camels. *Vet Parasitol.* 1997;69:49–54.
162. Singh Y, Pathak KML, Verma KC, Harsh D, Kapoor M. Prevalence and diagnosis of *Trypanosoma evansi* infection in camels in Rajasthan. *J Vet Parasitol.* 1997;11:133–6.
163. Singh N, Pathak KML, Kumar R. A comparative evaluation of parasitological, serological and DNA amplification methods for diagnosis of natural *Trypanosoma evansi* infection in camels. *Vet Parasitol.* 2004;126:365–73.
164. Narnaware SD, Ghorui SK, Kumar S, Patil NV. Vertical transmission of *Trypanosoma evansi* in dromedary camels and studies on fetal pathology, diagnosis and treatment. *Acta Parasitol.* 2016;61:329–36.

165. Iyer AR. Surra in bovines; some uncommon symptoms. *Indian Vet J.* 1948;24:298.
166. Muraleedharan K, Ziauddin KS, Hussain PM, Puttabatappa B, Seshadri SJ. Clinical signs of haemoparasitic infections of cattle of milk-shed areas on extensive cross breeding with exotic blood. *Vets Commun.* 2007;2:30–2.
167. Nair AS, Ravindran R, Lakshmanan B, Kumar SS, Tresamol PV, Saseendranath MR, et al. Haemoprotozoa of cattle in northern Kerala, India. *Trop Biomed (Kuala Lumpur).* 2011;28:68–75.
168. Shyma KP, Gupta SK, Singh A, Chaudhary SS, Gupta J. Monoclonal antibody based latex agglutination test for the diagnosis of trypanosomiasis in cattle. *J Adv Vet Res.* 2012;2:1–4.
169. Singh NK, Singh H, Jyoti HM, Rath SS. Prevalence of parasitic infections in cattle of Ludhiana district, Punjab. *J Parasit Dis.* 2012;36:256–9.
170. Agrawal V, Das G, Nath S. Incidence of *Trypanosoma evansi* in cross breed cattle in Indore, Madhya Pradesh. *Environ Ecol.* 2013;31:1635–7.
171. Kundu K, Tewari AK, Kurup SP, Baidya S, Rao JR, Joshi P. Sero-surveillance for surra in cattle using native surface glycoprotein antigen from *Trypanosoma evansi*. *Vet Parasitol.* 2013;196:258–64.
172. Bal MS, Sharma A, Ashuma BBK, Kaur P, Singla LD. Detection and management of latent infection of *Trypanosoma evansi* in a cattle herd. *Indian J Anim Res.* 2014;48:31–7.
173. Ware F. Surra in a oack of foxhounds. *J Comp Pathol Ther.* 1928;41:249–54.
174. Walley RSJ. Surra in fox-hounds. *J Comp Pathol Ther.* 1893;6:285–6.
175. Singh B, Kalra IS, Gupta MP, Nauriyal DC. *Trypanosoma evansi* infection in dogs: seasonal prevalence and chemotherapy. *Vet Parasitol.* 1993;50:137–41.
176. Balakrishnan VS, Alex PC, Babu KMJ, Saseendranath MR. Canine trypanosomiasis. *Cheiron.* 1994;23:93–6.
177. Arora N, Kumar A, Sharma SD. A case of *Trypanosoma evansi* infection in a Pomeranian dog. *Vet Pract.* 2003;4:23–4.
178. Krishnamoorthy P. A case of canine trypanosomiasis. *Intas Polivet.* 2005;6:203.
179. Varshney JP. Treatment aspects of naturally occurring trypanosomiasis in dogs - a clinical study. *Intas Polivet.* 2005;6:200–2.
180. Vatsya S, Garg R, Kumar RR, Yadav CL, Banerjee PS. Retrospective study on the incidence of gastrointestinal and blood parasites in dogs at Pantnagar and their public health significance. *J Vet Public Heal.* 2010;8:29–32.
181. Sharma A, Sharma B, Kumar A, Tiwari M, Ramsagar. Incidence of haemoprotozoan infection in canines in and around Mathura. *Vet Pract.* 2011;12:149–50.
182. Prasad KL, Kondaiah PM, Rayulu VC, Srilatha C. Prevalence of canine trypanosomiasis in certain areas of Andhra Pradesh. *J Parasit Dis.* 2015;39:238–40.
183. Lavanya KV, Gudewar JG, Pednekar RP, Gatne ML. Epidemiological, clinical, haemato-biochemical and therapeutic evaluation of canine trypanosomiasis in Mumbai. *Indian J Anim Sci.* 2016;86:372–5.
184. Reddy BS, Kumari KN, Sivajothi S, Rayulu VC. Haemato-biochemical and thyroxin status in *Trypanosoma evansi* infected dogs. *J Parasit Dis.* 2016;40:491–5.
185. Kumar R, Kumar S, Khurana SK, Yadav SC. Development of an antibody-ELISA for seroprevalence of *Trypanosoma evansi* in equids of north and north-western regions of India. *Vet Parasitol.* 2013;196:251–7.
186. Sinha BP, Verma SP, Kaushik SK. Successful treatment of acute clinical surra in an elephant. *Intas Polivet.* 2002;3:131–3.
187. Jana D, Jana M. Report on trypanosomiasis in a black Bengal buck. *Intas Polivet.* 2005;6:204.
188. Bharkad GP, Bhikane AU, Raote YV, Markandeya NM, Khan MA. Surra in a Kathiawari mare - a case report. *Intas Polivet.* 2005;6:205–6.
189. Bhardwaj RK, Singh J. Trypanosomiasis in a pregnant mare - a case report. *Centaurus.* 2007;24:31–3.
190. Chaudhary PS, Varshney JP, Deshmukh VV. Diagnosis and treatment of trypanosomiasis in equines: report of fifteen cases. *Intas Polivet.* 2008;9:274–8.
191. Laha R, Sasmal NK. Endemic status of *Trypanosoma evansi* infection in a horse stable of eastern region of India - a field investigation. *Trop Anim Health Prod.* 2008;40:357–61.
192. Laha R, Sasmal NK. Detection of *Trypanosoma evansi* infection among parasitologically and immunologically negative animals by polymerase chain reaction. *J Protozool Res.* 2010;20:7–11.
193. Mavadiya SV, Raval SK, Mehta SA. Epidemiological aspects of *Trypanosoma evansi* infection in horses. *Indian J F Vet (Indore).* 2010;6:51–3.
194. Sumbria D, Singla LD, Sharma A, Moudgil AD, Bal MS. Equine trypanosomiasis in central and western Punjab: prevalence, haemato-biochemical response and associated risk factors. *Acta Trop.* 2014;138:44–50.
195. Shegokar VR, Powar RM, Joshi PP, Bhargava A, Dani VS, Katti R, et al. Human trypanosomiasis caused by *Trypanosoma evansi* in a village in India: preliminary serologic survey of the local population. *Am J Trop Med Hyg.* 2006;75:869–70.
196. Dey S. CATT/T. *evansi* antibody levels in patients suffering from pyrexia of unknown origin in a tertiary care hospital in Kolkata. *Res J Pharm, Biol Chem Sci.* 2014;5:334–8.
197. Gill BS, Singh J, Gill JS, Kwatra MS. *Trypanosoma evansi* infection in pigs in India. *Vet Rec.* 1987;120:92.
198. Rao KM. Surra, a note on its prevalence in equines in East Godavari District during the last five years. *Indian Vet J.* 1947;24:189.
199. Sivajothi S, Rayulu VC, Malakondaiah P, Sreenivasulu D, Reddy BS. Detection of antibodies against *Trypanosoma evansi* in sheep by indirect ELISA in Rayalaseema region of Andhra Pradesh. *J Adv Vet Res.* 2014;4:88–92.
200. Upadhye SV, Dhoot VM. Trypanosomiasis in a tiger (*Panthera tigris*). *Zoo's Print Journals.* 2000;15:326.
201. Kulkarni HV. Equine and bovine surra; its incidence in Baroda State during the year 1944 and 1945. *Indian Vet J.* 1946;23:233–8.
202. Sivajothi S, Rayulu VC, Reddy BS. Development of slide enzyme linked immunosorbent assay (SELISA) for detection of *Trypanosoma evansi* infection in bovines. *J Adv Vet Res.* 2012;2:15–7.
203. Yadav SC, Kumar R, Manuja A, Goyal L, Gupta AK. Early detection of *Trypanosoma evansi* infection and monitoring of antibody levels by ELISA following treatment. *J Parasit Dis.* 2014;38:124–7.
204. Payne RC, Sukanto IP, Graydon R, Saroso H, Jusuf SH. An outbreak of trypanosomiasis caused by *Trypanosoma evansi* on the island of Madura, Indonesia. *Trop Med Parasitol.* 1990;41:445–6.
205. Payne RC, Sukanto IP, Djauhari D, Jones TW. *Trypanosoma evansi* infection in bovine and buffalo calves in Indonesia. *Vet Parasitol.* 1991;38:253–6.
206. Payne RC, Sukanto IP, Djauhari D, Partoutomo S, Wilson AJ, Jones TW, et al. *Trypanosoma evansi* infection in cattle, buffaloes and horses in Indonesia. *Vet Parasitol.* 1991;38:109–19.
207. Payne RC, Waltner-Toews D, Djauhari D, Jones TW. *Trypanosoma evansi* infection in swamp buffalo imported into Central Java. *Prev Vet Med.* 1991;11:105–14.
208. Davison HC, Thrusfield MV, Husein A, Muharsini S, Partoutomo S, Rae P, et al. The occurrence of *Trypanosoma evansi* in buffaloes in Indonesia, estimated using various diagnostic tests. *Epidemiol Infect.* 2000;124:163–72.
209. Boid R, Mleche WC. Isoenzyme analysis of stocks of trypanosomes isolated from cattle in Indonesia. *Res Vet Sci.* 1985;39:388–9.
210. Payne RC, Ward DE, Usman M, Rusli A, Djauhari D, Husein A. Prevalence of bovine haemoparasites in Aceh Province of northern Sumatra: implications for imported cattle. *Prev Vet Med.* 1988;6:275–83.
211. Payne RC, Sukanto IP, Partoutomo S, Sitepu P, Jones TW. Effect of suramin treatment on the productivity of feedlot cattle in a *Trypanosoma evansi* endemic area of Indonesia. *Trop Anim Health Prod.* 1994;26:35–6.
212. Ekawasti F, Wardhana AH, Sawitri DH, Dewi DA, Akbari RA. Serological test for surra cases in Lombok Island. *Proceedings of International Seminar on Livestock Production and Veterinary Technology 2016.* Bogor: Indonesian Center for Animal Science Research and Development (ICARD); 2017. p. 183–90.
213. Sawitri DH, Wardhana AH, Dewi DA, Ekawasti F, Widjaja E. Application of dried blood sample on Whatman filter paper for detection of *Trypanosoma evansi* from cattle in central Kalimantan by internal transcriber spacer-1 polymerase chain reaction. *Proceedings of International Seminar on Livestock Production and Veterinary Technology 2016.* Bogor: Indonesian Center for Animal Science Research and Development (ICARD); 2017. p. 191–7.
214. Derakhshanfar A, Mozaffari AA, Zadeh AM. An outbreak of trypanosomiasis (surra) in camels in the southern Fars Province of Iran: clinical, hematological and pathological findings. *Res J Parasitol.* 2010;5:23–6.
215. Sazmand A, Rasooli A, Nouri M, Hamidnejat H, Hekmatimoghaddam H. Serobiochemical alterations in subclinically affected dromedary camels with *Trypanosoma evansi* in Iran. *Pak Vet J.* 2011;31:223–6.
216. Pourjafar M, Badiei K, Sharifiyazdi H, Chalmeh A, Naghib M, Babazadeh M, et al. Genetic characterization and phylogenetic analysis of *Trypanosoma evansi* in Iranian dromedary camels. *Parasitol Res.* 2013;112:899–903.
217. Ahmadi-Hamedani M, Ghazvinian K, Darvishi MM. Hematological and serum biochemical aspects associated with a camel (*Camelus dromedarius*) naturally infected by *Trypanosoma evansi* with severe parasitemia in Semnan, Iran. *Asian Pac J Trop Biomed.* 2014;4:743–5.

218. Khosravi A, Hakimi Parizi M, Bamorovat M, Borhani Zarandi M, Mohammadi MA. Prevalence of *Trypanosoma evansi* in camels using molecular and parasitological methods in the southeast of Iran, 2011. *J Parasit Dis*. 2015;39:422–5.
219. Sazmand A, Eigner B, Mirzaei M, Hekmatimoghaddam SH, Harl J, Duscher GG, et al. Molecular identification of hemoprotozoan parasites in camels (*Camelus dromedarius*) of Iran. *Iran J Parasitol*. 2016;11:568–73.
220. Al-Abadi B, Al-Badrani B. Cattle blood analyses for parasitic infestation in Mosul, Iraq. *Res Opin Anim Vet Sci*. 2012;2:535–43.
221. Al-Rawashdeh O, Sharif LA, Al-Qudah K, Al-Ani F. *Trypanosoma evansi* infection in camels in Jordan. *Rev Elev Med Vet Pays Trop*. 1999;52:233–7.
222. Al-Taqi MM. Characterization of *Trypanosoma (Trypanozoon) evansi* from dromedary camels in Kuwait by isoenzyme electrophoresis. *Vet Parasitol*. 2011;32(11):835–41.
223. Pumhom P, Pognon D, Yangtara S, Thapathorn N, Milocco C, Douangboupha B, et al. Molecular prevalence of *Trypanosoma* spp. in wild rodents of Southeast Asia: influence of human settlement habitat. *Epidemiol Infect*. 2014;142:1221–30.
224. Anonymous. Surra in the Federated Malay States. *J Comp Pathol Ther*. 1909;22:185–92.
225. Jesse FFA, Asinamai AB, Abba Y, Muhammad AS, Idris UH, Chung LTE, et al. A clinical case of bovine trypanosomosis in an endemic farm in Malaysia. *J Adv Vet Anim Res*. 2016;3:286–91.
226. Rahman WA, Fong S, Chandrawathani P, Nurulaini R, Zaini CM, Premalaatha B. Comparative seroprevalences of bovine trypanosomiasis and anaplasmosis in five states of Malaysia. *Trop Biomed*. 2012;29:65–70.
227. Nurulaini R, Jamnah O, Adnan M, Zaini CM, Khadyah S, Rafiah A, et al. Mortality of domesticated java deer attributed to surra. *Trop Biomed*. 2007;24:67–70.
228. Adrian MS, Sani RA, Hassan L, Wong MT. Outbreaks of trypanosomiasis and the seroprevalence of *T. evansi* in a deer breeding centre in Perak, Malaysia. *Trop Anim Health Prod*. 2010;42:145–50.
229. Rajamanickam C, Wiesenhutter E, Zin FM, Hamid J. The incidence of canine haematozoa in Peninsular Malaysia. *Vet Parasitol*. 1985;17:151–7.
230. Elshafie EI, Sani RA, Hassan L, Sharma R, Bashir A, Abubakar IA. Active infection and morphometric study of *Trypanosoma evansi* among horses in Peninsular Malaysia. *Trop Biomed*. 2013;30:444–50.
231. Elshafie EI, Sani RA, Hassan L, Sharma R, Bashir A, Abubakar IA. Seroprevalence and risk factors of *Trypanosoma evansi* infection in horses in Peninsular Malaysia. *Res Vet Sci*. 2013;94:285–9.
232. Vellayan S, Mohamad A, Radcliffe RW, Lowenstine LJ, Epstein J, Reid SA, et al. Trypanosomiasis (surra) in the captive Sumatran rhinoceros (*Dicerorhinus sumatrensis sumatrensis*) in Peninsular Malaysia. *Animal health: a breakpoint in economic development? The 11th International Conference of the Association of Institutions for Tropical Veterinary Medicine and 16th Veterinary Association Malaysia Congress, 23–27 August 2004, Petaling Jaya, Malaysia; 2004*. p. 187–9.
233. Muhammad G, Saqib M, Sajid MS, Naureen A. *Trypanosoma evansi* infections in Himalayan black bears (*Selenarctos thibetanus*). *J Zoo Wildl Med*. 2007;38:97–100.
234. Shahid M, Janjua S, Abbas F, Burbach JS. PCR-based detection of *Trypanosoma evansi* infection in semi-captive Asiatic black bears (*Ursus thibetanus*). *Pak Vet J*. 2013;33:442–5.
235. Shahzad W, Munir R, Khan MS, Ahmad MD, Ijaz M, Ahmad A, et al. Prevalence and molecular diagnosis of *Trypanosoma evansi* in Nili-Ravi buffalo (*Bubalus bubalis*) in different districts of Punjab (Pakistan). *Trop Anim Health Prod*. 2010;42:1597–9.
236. Shahzad W, Munir R, Khan MS, Ahmad MUD, Iqbal M. Molecular diagnosis and chemotherapy of *Trypanosoma evansi* in Nili-Ravi buffaloes at district Okara (Pakistan). *J Anim Plant Sci*. 2012;22:212–6.
237. Shah SR, Phulan MS, Memon MA, Rind R, Bhatti WM. Trypanosomes infection in camels. *Pak Vet J*. 2004;24:209–10.
238. Hasan MU, Muhammad G, Gutierrez C, Iqbal Z, Shakoora A, Jabbar A. Prevalence of *Trypanosoma evansi* infection in equines and camels in the Punjab region, Pakistan. *Ann N Y Acad Sci*. 2006;1081:322–4.
239. Bhutto B, Gadahi JA, Shah G, Dewani P, Arijo AG. Field investigation on the prevalence of trypanosomiasis in camels in relation to sex, age, breed and herd size. *Pak Vet J*. 2010;30:175–7.
240. Durrani AZ, Bashir Z, Rasheed I, Sarwar N-A. Epidemiological study of common diseases and their risk factors in camels in South Punjab, Pakistan. *Microb Pathog*. 2017;108:6–12.
241. Rashid I, Firyal S, Tariq A, Muhammad G, Saqib M, Zafar MS. Use of Cymelarsan® and manganese chloride for treatment of the canine trypanosomiasis (surra): a research report. *Adv Anim Vet Sci*. 2014;2:104–5.
242. Waheed MA, Qureshi GH, Gondal JI. A report on surra in Gujranwala. *Pak Vet J*. 2003;23:153–4.
243. Gondal JI, Ahmad H. Zoonotic and infectious diseases: dealing with disease outbreaks: a report on surra (trypanosomiasis) in Gujranwala, Pakistan. Sixth International Colloquium on Working Equids: learning from others. Proceedings of an International Colloquium, New Delhi; 2010. p. 208–13.
244. Nadeem A, Aslam A, Chaudhary ZI, Ashraf K, Saeed K, Ahmad N, et al. Indirect fluorescent antibody technique based prevalence of surra in equines. *Pak Vet J*. 2011;31:169–70.
245. Stuart G, Krikorian KS. Observations on *Trypanosoma evansi* based on its occurrence in two outbreaks of surra in Palestine. *Trans R Soc Trop Med Hyg*. 1923;17:254–9.
246. Konnai S, Mingala CN, Sato M, Abes NS, Venturina FA, Gutierrez CA, et al. A survey of abortifacient infectious agents in livestock in Luzon, the Philippines, with emphasis on the situation in a cattle herd with abortion problems. *Acta Trop*. 2008;105:269–73.
247. Konnai S, Mekata H, Mingala CN, Abes NS, Gutierrez CA, Herrera JR, et al. Development and application of a quantitative real-time PCR for the diagnosis of surra in water buffaloes. *Infect Genet Evol*. 2009;9:449–52.
248. Laohasinnarong D, Kawazu S, Villacorte E, Leonardo L, Rivera P, Inoue N. Comparison of PCR and loop-mediated isothermal amplification (LAMP) for *Trypanosoma evansi* detection in water buffaloes of The Philippines. 13th Association of Institutions for Tropical Veterinary Medicine Conference 23–26 August 2010, Bangkok; 2010.
249. Villareal MV, Mingala CN, Rivera WL. Molecular characterization of *Trypanosoma evansi* isolates from water buffaloes (*Bubalus bubalis*) in the Philippines. *Acta Parasitol*. 2013;58:6–12.
250. Baticados WN, Fernandez CP, Baticados AM. Molecular detection of *Trypanosoma evansi* in cattle from Quirino Province, Philippines. *Vet Arh*. 2011;81:635–46.
251. Ochirkhuu N, Konnai S, Mingala CN, Okagawa T, Villanueva M, Pilapil FM. Molecular epidemiological survey and genetic analysis of vector-borne infections of cattle in Luzon Island, the Philippines. *Vet Parasitol*. 2015;212:161–7.
252. Omer OH, Magzoub M, Haroun EM, Mahmoudand OM, Abdelhamid YM. Diagnosis of *Trypanosoma evansi* in Saudi Arabian camels (*Camelus dromedarius*) by the passive haemagglutination test and Ag-ELISA. *J Veterinary Med Ser B*. 1998;45:627–33.
253. Amoudi MA, Al-Yousif M, Al-Shawa Y. Morphological forms of *Trypanosoma evansi* from blood of Arabian camel (*Camelus dromedarius*) in the Riyadh Metropolitan areas. *J Egypt Soc Parasitol (Cairo)*. 2011;41:29–34.
254. El-Wathig M, Faye B, Thevenon S, Ravel S, Bossard G. Epidemiological surveys of camel trypanosomosis in Al-Jouf, Saudi Arabia based on PCR and ELISA. *Emirates J Food Agric*. 2016;28:212–6.
255. Fernando SD, Jaysinghe JB. The use of spirotrypan in the treatment of surra in dogs. *Vet Rec*. 1965;77:44–5.
256. Lohr KF, Pohlpark S, Srikitjakarn L, Thaboran P, Bettermann G, Staak C. *Trypanosoma evansi* infection in buffaloes in north-east Thailand. I. Field investigations. *Trop Anim Health Prod*. 1985;17:121–5.
257. Kocher A, Desquesnes M, Kamyngkird K, Yangtara S, Leboucher E, Rodtian P, et al. Evaluation of an indirect-ELISA test for *Trypanosoma evansi* infection (surra) in buffaloes and its application to a serological survey in Thailand. *Biomed Res Int*. 2015;2015:361037.
258. Wuyts N, Chokesajjawatee N, Sarataphan N, Panyim S. PCR amplification of crude blood on microscope slides in the diagnosis of *Trypanosoma evansi* infection in dairy cattle. *Ann Soc Belg Med Trop (1920)*. 1995;75:229–37.
259. Tuntasuvan D, Sarataphan N, Nishikawa H. Cerebral trypanosomiasis in native cattle. *Vet Parasitol*. 1997;73:357–63.
260. Kashiwazaki Y, Pholpark M, Polsar C, Pholpark S. Haemoparasite infections in newly introduced dairy cattle in Loei Province, Thailand: *Trypanosoma evansi* antigen levels by ELISA referring to abortion. *Vet Parasitol*. 1998;80:99–109.
261. Pholpark S, Pholpark M, Polsar C, Charoenchai A, Paengpassa Y, Kashiwazaki Y. Influence of *Trypanosoma evansi* infection on milk yield of dairy cattle in northeast Thailand. *Prev Vet Med*. 1999;42:39–44.
262. Suteeraparp P, Pholpark S, Pholpark M, Charoenchai A, Chompoochan T, Yamane I, et al. Seroprevalence of antibodies to *Neospora caninum* and

- associated abortion in dairy cattle from central Thailand. *Vet Parasitol.* 1999; 86:49–57.
263. Kashiwazaki Y, Kanitpun R, Suteeraparp P, Boonchit S. A preliminary comparative study of a dipstick colloidal dye immunoassay and two antigen-detection ELISAs for diagnosis of *Trypanosoma evansi* infection in cattle. *Vet Res Commun.* 2000;24:533–44.
  264. Desquesnes M, Kamyngkird K, Kengradomkij C, Pruvot M, Sarataphan N, Jittapalpong S. Standardisation of an ELISA for *Trypanosoma evansi* and its application to dairy cattle in Thailand. Proceedings of the 15th Congress of the Federation of Asian Veterinary Associations - OIE Joint Symposium on emerging diseases, Bangkok, Thailand; 2008. p. 269–70.
  265. Tuntasuvan D, Mimapan S, Sarataphan N, Trongwongsa L, Intraraks R, Luckins AG. Detection of *Trypanosoma evansi* in brains of the naturally infected hog deer by streptavidin-biotin immunohistochemistry. *Vet Parasitol.* 2000;87:223–30.
  266. Thiptara A, Jeenpun A, Suknao K, Konkaew W, Worasing R, Anan S, et al. Epidemiological investigation on outbreaks of cervine trypanosomosis (surra) in rusa deer (*Cervus timorensis*) in Krabi Province of southern Thailand. Agricultural Innovation for Global Value Chain, Proceedings of 54th Kasetsart University Annual Conference, 2–5 February 2016, Kasetsart University, Thailand. Vol. 1, Plants, Animals, Veterinary Medicine, Fisheries, Agricultural Extension and Home Economics; 2016. p. 586–93.
  267. Barameechaihanun E, Suwannasaeng P, Boonbal N, Pattanee S, Hoisang S. Treatment of trypanosomiasis in dog. *J Mahanakorn Vet Med.* 2009;4:51–60.
  268. Pintavongs W, Chueplavej P, Boonyasart B, Kidyhoo S, Pravai W, Rattanakunuprakarn J, et al. Domestic elephant population structure and health status in Thailand. *Kasetsart Vet.* 2014;24:16–24.
  269. Holland WG, Thanh NG, Do TT, Sangmaneedet S, Goddeeris B, Vercruyse J. Evaluation of diagnostic tests for *Trypanosoma evansi* in experimentally infected pigs and subsequent use in field surveys in north Vietnam and Thailand. *Trop Anim Health Prod.* 2005;37:457–67.
  270. Jittapalpong S, Inpankaew T, Sarataphan N, Herbreteau V, Hugot JP, Morand S, et al. Molecular detection of divergent trypanosomes among rodents of Thailand. *Infect Genet Evol.* 2008;8:445–9.
  271. Wernery U, Seifert HS, Billah AM, Ali M. Predisposing factors in enterotoxemias of camels (*Camelus dromedarius*) caused by *Clostridium perfringens* type A. *Rev Elev Med Vet Pays Trop.* 1991;44:147–52.
  272. Verloo D, Holland W, My LN, Thanh NG, Tam PT, Goddeeris B, et al. Comparison of serological tests for *Trypanosoma evansi* natural infections in water buffaloes from north Vietnam. *Vet Parasitol.* 2000;92:87–96.
  273. Holland WG, Thanh NG, My LN, Do TT, Goddeeris BM, Vercruyse J. Prevalence of *Trypanosoma evansi* in water buffaloes in remote areas in northern Vietnam using PCR and serological methods. *Trop Anim Health Prod.* 2004;36:45–8.
  274. Santa Cruz A, Comolli J, Ortiz J, González J, González A. Morphometric data of *Trypanosoma evansi* in capybaras (*Hydrochaeris hydrochaeris*) from Chaco Argentina. *Rev Vet.* 2013;24:60–2.
  275. Monzón CM, Jara A, Nantulya VM. Sensitivity of antigen ELISA test for detecting *Trypanosoma evansi* antigen in horses in the subtropical area of Argentina. *J Parasitol.* 1995;81:806–8.
  276. Gonzales JL, Jones TW, Picozzi K, Cuellar HR. Evaluation of a polymerase chain reaction assay for the diagnosis of bovine trypanosomiasis and epidemiological surveillance in Bolivia. *Kinetoplastid Biol Dis.* 2003;2:8.
  277. Gonzales JL, Chacon E, Miranda M, Loza A, Siles LM. Bovine trypanosomiasis in the Bolivian Pantanal. *Vet Parasitol.* 2007;146:9–16.
  278. Stevens JR, Nunes VLB, Lanham SM, Oshiro ET. Isoenzyme characterization of *Trypanosoma evansi* isolated from capybaras and dogs in Brazil. *Acta Trop.* 1989;46:213–22.
  279. Aquino LPCT, Machado RZ, Lemos KR, Marques LC, Garcia MV, Borges GP. Antigenic characterization of *Trypanosoma evansi* using sera from experimentally and naturally infected bovines, equines, dogs, and coatis. *Rev Bras Parasitol Vet.* 2010;19:112–8.
  280. Alves FM, Olifiers N, Bianchi R, Duarte AC, Cotias PMT, D'Andrea PS, et al. Modulating variables of *Trypanosoma cruzi* and *Trypanosoma evansi* transmission in free-ranging coati (*Nasua nasua*) from the Brazilian Pantanal region. *Vector Borne Zoonotic Dis.* 2011;11:835–41.
  281. Olifiers N, Jansen AM, Herrera HM, Bianchi R, D'Andrea PS, Mourão Gde M, et al. Co-infection and wild animal health: effects of trypanosomatids and gastrointestinal parasites on coatis of the Brazilian Pantanal. *PLoS One.* 2015;10:e0143997.
  282. Silveira JAG, Rabelo EM, Lacerda AC, Borges PA, Tomás WM, Pellegrin A, et al. Molecular detection and identification of hemoparasites in pampas deer (*Ozotoceros bezoarticus* Linnaeus, 1758) from the Pantanal Brazil. *Ticks Tick Borne Dis.* 2013;4:341–5.
  283. Savani ES, Nunes VL, Galati EA, Castilho TM, Araujo FS, Ilha IM, et al. Occurrence of co-infection by *Leishmania (Leishmania) chagasi* and *Trypanosoma (Trypanozoon) evansi* in a dog in the state of Mato Grosso do Sul, Brazil. *Mem Inst Oswaldo Cruz.* 2005;100:739–41.
  284. Colpo CB, Monteiro SG, Stainki DR, Colpo ETB, Henriques GB. Natural infection by *Trypanosoma evansi* in dogs. *Cienc Rural.* 2005;35:717 (In Portuguese).
  285. Franciscato C, Anjos Lopes ST, Teixeira MG, Monteiro SG, Wolkmer P, Garmatz BC, et al. Dog naturally infected by *Trypanosoma evansi* in Santa Maria RS Brasil. *Cienc Rural.* 2007;37:288 (In Portuguese).
  286. Silva AS, Zanette RA, Colpo CB, Santurio JM, Monteiro SG. Clinical signs in dogs naturally infected by *Trypanosoma evansi* (Kinetoplastida: Trypanosomatidae) in the State of Rio Grande do Sul, Brazil. *Clínica Veterinária.* 2008;13:66–8 (In Portuguese).
  287. Howes F, Silva AS, Athayde C, Costa MM, Corrêa MMB, Tavares KCS, et al. A new therapeutic protocol for dogs infected with *Trypanosoma evansi*. *Acta Sci Vet.* 2011;39:988.
  288. Coelho WMD, Coelho JCA, Teixeira WFP, Coelho NMD, Oliveira GP, Lopes WDZ, et al. Detection of co-infections by *Leishmania (L.) chagasi*, *Trypanosoma evansi*, *Toxoplasma gondii* and *Neospora caninum* in dogs. *Ars Vet.* 2013;29:169–74.
  289. Rodrigues A, Figuera RA, Souza TM, Lucia AS, Soares M, Milano J, et al. Outbreaks of trypanosomiasis in horses by *Trypanosoma evansi* in the State of Rio Grande do Sul, Brazil: epidemiological, clinical, hematological, and pathological aspects. *Pesqui Vet Bras.* 2005;25:239–49 (In Portuguese).
  290. Conrado AC, Lopes STA, Oliveira LSS, Monteiro SG, Vargas DLB, Bueno A. Natural infection by *Trypanosoma evansi* in horses in the central area of the State of Rio Grande do Sul, Brazil. *Cienc Rural.* 2005;35:928–31 (In Portuguese).
  291. Zanette RA, Schafer da Silva A, Machado da Costa M, Monteiro SG, Santurio JM, Anjos Lopes ST. Occurrence of *Trypanosoma evansi* in equines in Cruz Alta, RS, Brazil. *Cienc Rural.* 2008;38:1468–71 (In Portuguese).
  292. Silva AS, Andrade Neto OAS, Costa MM, Wolkmer P, Mazzantti CM, Santurio JM, et al. Trypanosomiasis in equines in southern Brazil. *Acta Sci Vet.* 2010; 38:113–20.
  293. Nunes JTS, da Silva AS, de Souza DF, Tonin AA, Lazzarotto C, Miletto LC, et al. Occurrence of *Trypanosoma evansi* in horses in the State of Minas Gerais, Brazil. *J Equine Vet Sci.* 2012;32:205–7.
  294. Herrera HM, Rademaker V, Abreu UGP, D'Andrea PS, Jansen AM. Variables that modulate the spatial distribution of *Trypanosoma cruzi* and *Trypanosoma evansi* in the Brazilian Pantanal. *Acta Trop.* 2007;102:55–62.
  295. Ramírez JD, Tapia-Calle G, Muñoz-Cruz G, Poveda C, Rendón LM, Hincapié E, et al. Trypanosome species in Neotropical bats: biological, evolutionary and epidemiological implications. *Infect Genet Evol.* 2014;22:250–6.
  296. Wells EA, D'Alessandro A, Morales GA, Angel D. Mammalian wildlife diseases as hazards to man and livestock in an area of the Llanos Orientales of Colombia. *J Wildl Dis.* 1981;17:153–62.
  297. Jaimes-Dueñez J, Triana-Chávez O, Mejía-Jaramillo AM. Parasitological and molecular surveys reveal high rates of infection with vector-borne pathogens and clinical anemia signs associated with infection in cattle from two important livestock areas in Colombia. *Ticks Tick Borne Dis.* 2017;8:290–9.
  298. Correa-Salgado A, Pacheco de Araujo FA, Cañón-Franco WA. Natural infection by *Trypanosoma evansi* in dog, Manizales - Colombia: case report. *Rev Ibero-Latinoam Parasitol.* 2010;69:98–100 (In Portuguese).
  299. Vokaty S, McPherson VO, Camus E, Applewhaite L. Ovine trypanosomiasis: a seroepidemiological survey in coastal Guyana. *Rev Elev Med Vet Pays Trop.* 1993;46:57–9.
  300. Muñoz K, Chávez A. *Trypanosoma evansi* isolated from capybara (*Hydrochaeris hydrochaeris*). *Mem Inst Oswaldo Cruz.* 2001;96:945–6.
  301. Arias JF, García F, Rivera M, López R. *Trypanosoma evansi* in capybara from Venezuela. *J Wildl Dis.* 1997;33:359–61.
  302. Perrone TM, Gonzatti MI, Villamizar G, Escalante A, Aso PM. Molecular profiles of Venezuelan isolates of *Trypanosoma* sp. by random amplified polymorphic DNA method. *Vet Parasitol.* 2009;161:194–200.
  303. Herrera EA, Castro Y. *Trypanosoma evansi* (Kinetoplastida: Trypanosomatidae) in capybaras (*Hydrochaeris hydrochaeris*): prevalence, effect and sexual selection. *Rev Biol Trop.* 2017;65:229–37.
  304. Ramirez-Iglesias JR, Elejalde MC, Reyna-Bello A, Mendoza M. Molecular diagnosis of cattle trypanosomes in Venezuela: evidences of *Trypanosoma evansi* and *Trypanosoma vivax* infections. *J Parasit Dis.* 2017;41:450–8.



305. Gutierrez C, Juste MC, Corbera JA, Magnus E, Verloo D, Montoya JA. Camel trypanosomosis in the Canary Islands: assessment of seroprevalence and infection rates using the card agglutination test (CATT/*T. evansi*) and parasite detection tests. *Vet Parasitol.* 2000;90:155–9.
306. Molina JM, Ruiz A, Juste MC, Corbera JA, Amador R, Gutiérrez C. Seroprevalence of *Trypanosoma evansi* in dromedaries (*Camelus dromedarius*) from the Canary Islands (Spain) using an antibody Ab-ELISA. *Prev Vet Med.* 2000;47:53–9.
307. Gutierrez C, Corbera JA, Juste MC, Doreste F, Morales I. An outbreak of abortions and high neonatal mortality associated with *Trypanosoma evansi* infection in dromedary camels in the Canary Islands. *Vet Parasitol.* 2005;130:163–8.
308. Gutiérrez C, Tamarit A, González-Martín M, Tejedor-Junco MT. Control and eventual eradication of *Trypanosoma evansi* infection in dromedary camels after an episodic outbreak in mainland Spain: an example in a non-endemic area. *Vet Parasitol.* 2014;204:153–7.

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