Review Article

Mammeri Adel*

Brucella transmission from domestic and wild animals to dromedary camel: Diagnostic methods and zoonotic threats – A review

https://doi.org/10.1515/ovs-2022-0113
received February 26, 2022; accepted August 28, 2022

Abstract: The present review discusses the transmission risk factors of camel (*Camelus dromedarius*) brucellosis in the limits of domestic and wild interfaces and zoonotic threats. The median position of the dromedary's life between wild and the domestic areas seems to increase the risks of brucellosis transmission, compared to other receptive domestic ruminants. In arid environments, canids, lagomorphs, rodents, and wild boars are potential reservoirs of *Brucella* spp. Dromedary camels raised according to a periurban breeding system are often in direct or indirect contact with wild animals, domestic animals, and humans. Constraints of brucellosis detection and control in wild animals, especially in developing countries, hamper preventing disease in camelids and related occupational categories. A total eradication of animal and human brucellosis, in developing countries, is faced by the difficulty of applying quarantine periods for suspected animals, the lack of reliable diagnostic tools, and the impossibility of controlling animals at the common grazing lands, livestock markets, and transboundary areas. In developing countries, the informal she-camel milk collection, the periurban camel breeding, and the shortage in the technological processing and the pasteurization of she-camel milk play a key role in brucellosis zoonotic transmission.Veterinarians should have more initiative in brucellosis control in both domestic and wildlife animals.

Keywords: periurban camel breeding system, brucellosis epidemiology, occupational disease, Arabian peninsula, African countries

*** Corresponding author: Mammeri Adel,** Department of Agronomic Sciences, Faculty of Sciences, University of M'sila, PB 166, M'sila 028000, Algeria; Laboratory of Genetics, Biotechnology, and Valorization of Bioresources, University of Biskra, Biskra 07000, Algeria, e-mail: adel.mammeri@univ-msila.dz,
tel: +213-066-5311-181
ORCID: Mammeri Adel 0000-0001-8798-322X

1 Introduction

Africa and Arabian peninsula are considered as the cradle of one-humped camel (*Camelus dromedarius*) [1]. As camels are still an important part of the nomadic and pastoral livelihoods and because of the lack of mandatory vaccination programmes for camels, the precise size of their population worldwide is difficult to be determined. It is estimated that the world population of camels is 25.89 million, composed of 11% two-humped (*Camelus bactrianus*) and 89% of one-humped dromedary camels (*C. dromedarius*) [2]. In Africa, Sudan takes the first place followed by Somalia than Ethiopia regarding the number of camels [1]. Many tribes in different parts of the Sudan depend entirely on camels for their livelihood [3]. In Algeria, she-camel milk is considered as an effective substance against several diseases in humans due to its authentic organoleptic and nutritional properties [4–6]. Among Gulf countries, for example in United Emirates, pastoral communities raise camels as social traditional activity and for economic income from meat and milk production [7]. The value of dromedaries is very high, especially in camel-racing countries [8].

Although brucellosis had been or was close to being eradicated from a number of developed countries, it continued to be a major public and animal health problem in many regions in the developing countries of the world [9]. Brucellosis is one of the most important zoonotic diseases in the world. It is an economically important disease in livestock resulting in abortion, still births, retained placenta, reduced milk yield, and infertility [10].

Camel brucellosis can be encountered in all camel-rearing countries with exception of Australia [11]. Among camels, the highest prevalence of brucellosis occurs in Egypt, Iran, and Saudi Arabia [12]. Camels are not known to be primary hosts of *Brucella* [13]. Brucellosis in dromedary camels can be caused by *Brucella abortus*, *Brucella melitensis*, and *Brucella ovis* [14]. Camels are susceptible to both *B. abortus* and *B. melitensis*. Consequently, the prevalence depends upon the infection rate in primary hosts being in contact with them [13].

Although brucellosis in camels has been reviewed extensively, there has not been sufficient emphasis on the camel's critical role at the interface between humans and both wild and domestic animal populations. The median ecological position of the dromedary camel between domestication and wildlife seems to be an emblematic issue in the epidemiology of camel brucellosis.

Camelids play a crucial role in human communities located in dry, sometimes harsh and even hostile, environments such as deserts or high mountains (small camelids) [15]. Both environments, the desert and the mountains, are generally considered to be part of the wildlife areas. Nevertheless, it is often very difficult to draw visible and well-defined boundaries between urban and wild areas, especially where camel husbandry is practised. Dromedaries are usually considered as domestic animals, although they spend a large part of their lives in an ambulatory state in the wild lands, searching for food or travelling in caravans. Thus, it could be said that the dromedary leads a double life: both wild and domestic.

C. dromedarius is an almost exclusively domesticated species that is common in arid areas as both beasts of burden and production animals for meat and milk, with highest numbers in Africa and the Middle East [16]. Currently, there is increasing need to determine whether camels are clinically susceptible, as potential reservoirs and maintenance or bridge hosts, to viral pathogens affecting small ruminants, cattle, and/or humans. Overall, dromedaries seem to be more resistant hosts for bovine, ovine, or caprine viral diseases such as foot-and-mouth disease or rinderpest [15]. At present, the ability of camels to act as a point source or vector for disease is a concern due to increasing human demands for meat, lack of biosafety and biosecurity protocols in many regions, and a growth in the interface with wildlife as camel herds become sympatric with non-domestic species [16].

The present review is built on the author's longstanding interest in zoonotic risks of brucellosis, especially in rural and nomadic communities in Algeria [5,17–21]. The objective of this article is to highlight the epidemiology of brucellosis and the risk factors for transmission in camel herds, focusing on the domestic and wild animal species that could transmit brucellosis to camels. Second, the available diagnostic techniques for brucellosis in domestic and wild animals are outlined. This synthesis is used afterward to establish hypothetical conceptual schemes of zoonotic threats and transmission from one animal species to another and to propose recommendations for brucellosis control and eradication in the light of the latest scientific data.

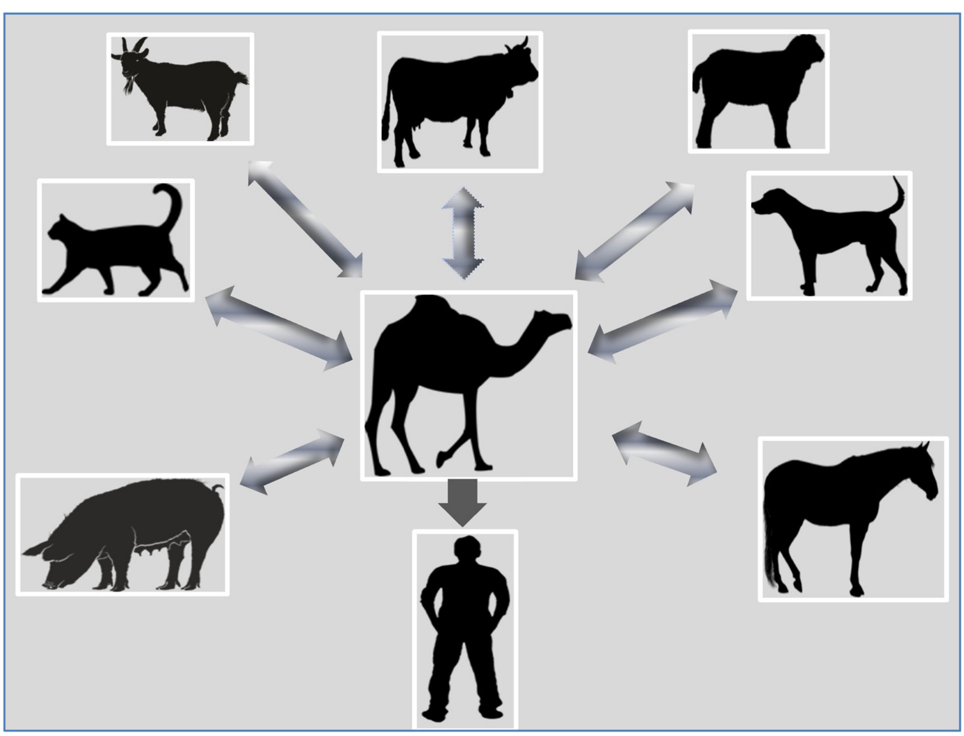

Figure 1: Possible transmission way scheme of *B. melitensis* and *B. abortus* from *C. dromedarius* to susceptible domestic animals and human (Mammeri).

2 Brucellosis epidemiology and contagion risk factors from domestic animals to camels

Brucellosis has a worldwide distribution and affects cattle, pigs, sheep, goats, camelids, dogs, and, occasionally, horses (Figure 1) [8].

Brucellosis prevalence depends on husbandry and management practices, presence of reactor animals in the region, continuous movement of infected camels, absence of veterinary service, and lack of awareness about the disease in camels. High animal and herd prevalence had been reported from numerous countries, which increases the spread of infection through uncontrolled trade of clinically suspected animals [22]. This clearly indicates that camel brucellosis is as hazardous as that of bovine and small ruminants [23].

B. melitensis infections had been reported occasionally in cattle, camels, and dogs and rarely in horses and pigs [24]. Small ruminants are infectious after either abortion or full-term parturition. Goats usually shed *B. melitensis* in vaginal discharges for at least 2–3 months, but shedding usually ends within 3 weeks in sheep, while shedding in milk and semen can be prolonged or lifelong, particularly in goats. Kids and lambs that nurse from infected dams may shed *B. melitensis* in the faeces [25]. Several studies conducted by Mammeri [17,18,20] and Mammeri et al. [19,21] have shown that brucellosis exists as an insidious enzootic infection and that it is considered a major cause of abortions in small ruminants raised in the steppe regions of Algeria.

Furthermore, *B. melitensis* was identified in a sample of cat fleas (*Ctenocephalides felis*) collected from equal number of cats and dogs residing in semiurban and urban areas of Attica region (Greece). Authors suspect flea or cat contact with wild rodents. Since *C. felis* is the most prevalent ectoparasite of pet animals with cosmopolitan distribution, obligatory haematophagous, and may prey on humans to receive bloodmeals, the proximity of the cats and their fleas with humans indicate a risk for public health [26].

In a study carried out in Korea, dogs were infected with *B. abortus* [24]. In Egypt, *Brucella abortus bv1* was identified in uterine discharge of apparently healthy bitch and queen with open pyometra housed on a cattle farm. This study highlights the role of dogs and cats as asymptomatic carriers and reservoir for *Brucella* [27]. In a recent study conducted in Pakistan by Jamil et al. [28], results point toward a risk of brucellosis transmission from dog to livestock and humans and *vice versa*. The same study expects to draw the attention of concerned authorities towards infection prevention and animal welfare. According to Coelho et al. [29], dogs play an important role in the diffusion of brucellosis, acting as mechanical disseminators by feeding on aborted foetuses, dragging them along, and spreading the bacteria. Insects on dogs could act as a mechanical vector of brucellosis. Blood-sucking insects have been reported as disseminators of brucellosis. However, stray dogs which remain free on the streets and travel long distances also act as disseminators of the agent and provide chances for infection of other animals and humans through environmental contamination. Zemmouri et al. [21] reported regarding brucellosis in Algeria that companion and guard animals, especially dogs and cats, would play the role of reservoir responsible for shedding *Brucella* and eventually other zoonotic agents, and thus they should be considered as veritable contaminators for their environment.

The study of Madu et al. [30] showed that *Brucella* antibodies are present in camels of Nigeria with the infection possibly as a result of contact with infected cattle. Coelho et al. [29] reported the influence of the agro-ecological zone as a brucellosis risk factor, having a higher prevalence in dry zones. As grazing areas are very scarce in dry lands, animals have to search for food on restricted rangelands, which implies unlimited contact between animals with potential transmission of pathogens. The use of common pasture areas or improper cleaning and disinfection procedures in farms and breeding several species on the same surface have been described as risk factors of contagion due to multiple sources of infection. Our findings are supported by the results reported by Ullah et al. [31].

3 Brucellosis epidemiology and contagion risk factors of dromedary camel from wild animals

Brucella infections have been documented worldwide in a great variety of wildlife species and in marine mammals [8]. Furthermore, the potential impact of marine *Brucellae* in coastal areas where stranded cetaceans may come into contact with domestic animals and thus scavenging animals or humans should be investigated [32].

For camelid brucellosis, Dadar et al. [2] showed that geographical location, sex, herd size, age, and mixed rearing are important risk factors for brucellosis in camels.

Also, the prevalence of brucellosis is higher among adult camels >4 years old compared to 6 months to 4-year-old animals. Furthermore, Benfodil et al. [33], regarding camel brucellosis in Algeria, showed a higher seroprevalence in animals living in flocks with a history of abortion and females (P = 0.01). Waktole et al. [34] reported that among the risk factors assessed, only abortion and body condition disclosed a statistically significant difference ($P < 0.05$) with regard to the seropositivity of camel brucellosis in Eastern Ethiopia.

Wild animals, such as hare and wild boar, can sometimes constitute a reservoir of *Brucellae* with the possibility of accidental transmission to domestic ruminants. Infected animals emit contaminated substances into the environment through their contents of the pregnant uterus, vaginal secretions, urine, milk, semen, and suppurative products [35]. During a study conducted in Tuscany region (Central Italy), among 374 wild boar (*Sus scrofa*) sera, 2 (0.53%) were tested positive to *Brucella* spp. This animal could contribute to maintaining and/or disseminating some bacterial or viral pathogens to humans, especially hunters and domestic animals, especially in free range farms [36].

Brucellosis of the hare may be due to *B. abortus*, *B. melitensis*, or *B. suis* (biovars 1 or 3), but most often it is consecutive to infection with *B. suis* biovar2. The pathogenicity of this biovar (*B. suis* biovar2) is naturally adapted to the hare, sometimes leading to general septic-pyohemic and genital involvement [37].

A co-adaptation of *Brucella* with terrestrial wild carnivore hosts is not as straightforward as in domestic animals. Wild carnivores often carry the same pathogens as their domesticated relatives (cats and dogs), but the risk of exposure varies widely because of differences in biology, distribution, and historical interactions [38]. According to Kosoy and Goodrich [38], *B. abortus* was identified in Spotted hyena (*Crocuta crocuta*), Golden jackal (*Canis aureus*), Coyote (*Canis latrans*), Wolf (*Canis lupus*), Black-backed jackal (*Canis mesomelas*), and several fox species (Figure 2).

Rats are known to be infected with *Brucella*. Vertical transmission of brucellosis was recorded in rats. Also, it had been confirmed that rats born to infected dams may become latent carriers of *B. abortus* infection potentially providing a reservoir for future transmission [39].

Bats (*Chiroptera* spp.) represent one of the most successfully evolved mammalian groups on Earth for their unique characteristics, such as a long lifespan, the capability to fly long distances during foraging and particularly during seasonal migrations, the ability to inhabit a multitude of diverse ecological niches, and the colonial habitation. Bats have zoonotic potential for bartonellosis, brucellosis, and leptospirosis [40].

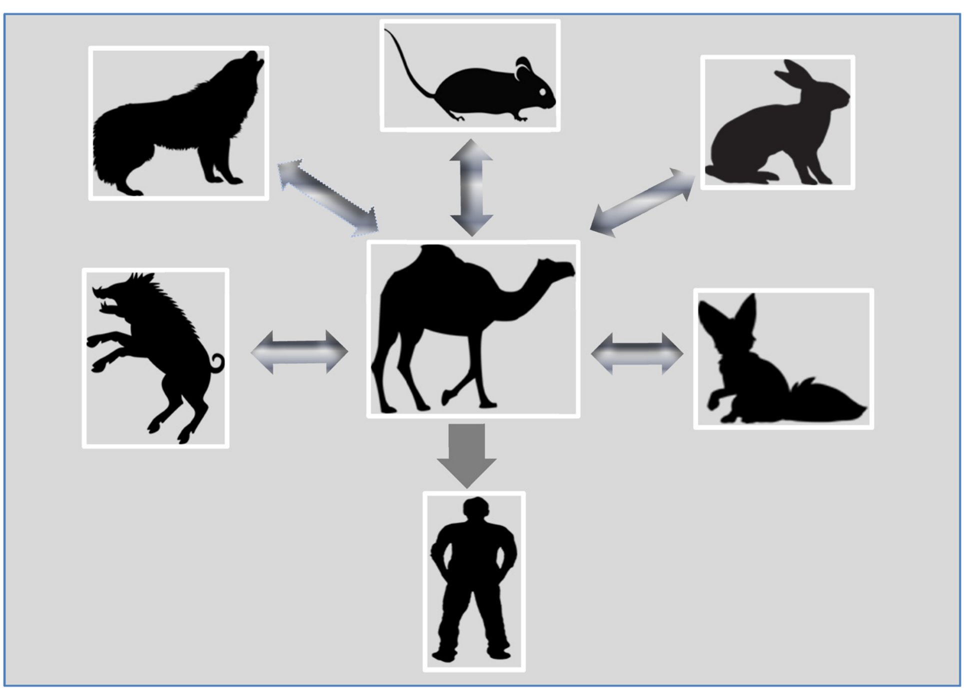

Figure 2: Possible transmission way scheme of *B. melitensis* and *B. abortus* from *C. dromedarius* to susceptible wild animals and human (Mammeri).

4 Brucellosis zoonotic threats from dromedary camel and the resulting foodstuffs

The main characteristic of the *Brucella* genus is its ability to survive within phagocytic and non-phagocytic cells [28]. Four species of *Brucellae* cause human disease: *B. melitensis*, *B. suis*, *B. abortus*, and *B. canis* in descending order of pathogenicity. *B. melitensis* remains fully virulent for man after infecting cattle. Camels infected with *B. melitensis* shed the organisms in milk and in some countries this is a serious public health problem [36]. Despite vaccination campaigns, *B. melitensis* remains the principal cause of serious human brucellosis [11,41].

The hardiness of camels in arid regions has made humans more dependent on them, especially as a stable protein source. However, camels carry and may transmit disease-causing agents to humans and other animals [16]. Generally, human being can be infected with brucellosis through various routes: consumption of contaminated dairy products, microbial inoculation through cuts or abrasions in the skin surface, conjunctiva inoculation, inhalation of infectious aerosols, accidental human contact with infected animals, and consumption of contaminated meat [42]. Certain occupations are associated with a high risk of infection with brucellosis, where direct and environmental contamination may present hazards (Figure 3) [36]. Thus, in a study conducted by Mammeri [17,19] on occupational brucellosis in Biskra Governorate (Algeria), it had been found that 41.93% of private veterinarians have been affected by brucellosis during their professional careers.

Camel populations, particularly in sub-Saharan Africa, are increasing exponentially in response to prolonged droughts, and thus, the risk of zoonoses increases as well [16]. For example, in a study carried out by Osoro et al. [43], in Kenya, on univariate analysis, risk factors identified as significantly ($P < 0.05$) associated with human household brucellosis seropositivity included ownership or camels, pastoralist production system, nomadism, natural breeding (as opposed to artificial insemination), acquisition of new animals into farm, regularly ingesting raw milk, and exposure to livestock (herding, feeding, and milking). In the same study, the odds were greatest for households where camels were seropositive for brucellosis.

High herd prevalence and uncontrolled trade of clinically suspected animals pose a continuous risk for human infection [22]. Traditional husbandry and poor management practices, mixing with other animals, and unrestricted movement of camels led to the spread of the disease [13], especially, uncontrolled trade of clinically inconspicuous

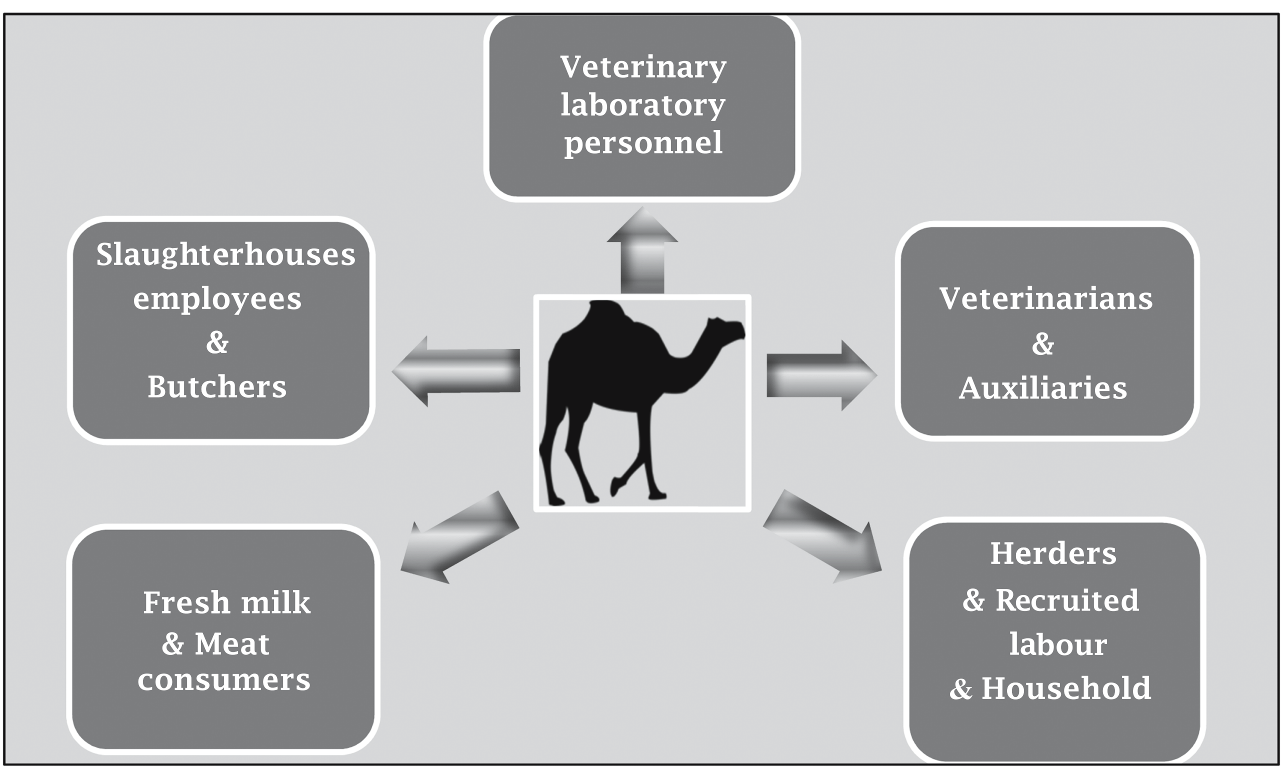

Figure 3: Socioprofessional and consumers' categories at risk to contract camelids' brucellosis (Mammeri).

animals [11]. In the North African region, given the importance of trade flows based on the export of live animals, especially since these flows are often informal, veterinary border controls are difficult to be implemented systematically [44].

Brucellosis food-borne transmission includes consumption of unpasteurized camel milk and raw meat, medicinal use of camel urine, and zoonotic transmission from other species [45]. Water sources, such as wells, may also be contaminated by recently aborted animals or by run-off of rain water from contaminated areas [36]. The fact that nomad populations have a preference to she-camel raw milk [4–6] could be an important factor to increase risks for *Brucellae* infections through these populations. The camel milk is consumed in raw state by camel keeper and positive effect of camel milk on diabetic patients has been studied in India [7]. Thus, for the reason of treating several diseases, Algerian consumers have a great preference to she-camel raw milk [4,6].

In many countries, the consumption of "healthy foods" has become fashionable. These often include unpasteurized milk or milk products and may pose a particular risk. There is often considerable resistance to accepting that such "healthy" products can be dangerous. Raw vegetables may be contaminated by infected animals and present a hazard. In endemic areas, tourists consuming "ethnic" food products may be particularly at risk [36]. In Algeria, through several research studies carried out by Mammeri [4–6], author concluded that camel breeding, conducted in a periurban mode, generates high risks of contamination among breeders and their households, as well as among potential consumers of she-camel milk, especially since camel milk is often consumed in a raw state, without being heated, in order to take advantage of its therapeutic properties, according to the convictions of the majority of consumers.

Since several decades, there has been a radical change in dromedary camel farming practices in the Arabian Peninsula with an intensification of the production and a concentration of the production around cities and as periurban breeding system [4,6,45]. This fact increased the frequency of zoonotic infections from camels to humans [45]. Mammeri [4] mentioned that in Algeria, the relative lack of collaboration between formal milk collectors and periurban camel herders is mainly due to the lack of manufacturing units for the conservation, technological processing, and pasteurization of she-camel milk.

Mammeri [4–6] reported the specificities of camel periurban breeding system in Algeria, such as raw milk marketing, close proximity to consumers, unsatisfactory hygienic status, shortage of raw milk storage equipment, scarcity of electric energy sources, lack of vulgarization as well as herders' low level of school education. In the camel periurban breeding system, buyers of she-camel milk are often transient motorists who usually reside far from the sites of camel herds, so that later, at the time of reporting possible outbreaks, it would be difficult to trace the source of infection, especially since milk buyers include dairy traders who transport large quantities of she-camel milk for resale to unknown potential consumers living in other regions. According to Mammeri [5], it seems being necessary to consider the coexistence of small ruminants breeding nomadic system and camel periurban breeding system as an important risk factor for brucellosis persistence and dissemination.

In nomadic societies, the adult humans have often been exposed to infection at an early age and do not manifest acute disease, although many may have sequelae from chronic infection. However, children account for a high proportion of acute cases and brucellosis is mostly a paediatric problem [36]. As long as the disease persists in the animal reservoir and the pastoralists continue to drink raw camel milk, the prevalence of human brucellosis, in the area, is bound to increase [46]. Tourists or travellers to endemic areas may acquire brucellosis, usually by consumption of unpasteurized milk or other dairy products. They may also import infected cheeses or other dairy products into their own countries and infect their families [36].

Zoonotic infections remind us that for all the shared benefits of long-term human and animal relationships, the close interactions between animals of different species can also yield unwanted consequences and require new protocols and approaches to mitigate disease transmission [47]. However, in practice One Health research is still relatively limited to the animal and medical sciences, with leanings towards positivist paradigms. There are strong calls for One Health to better embrace the social sciences and to more strongly value human subjectivity and active participation to fulfil its aims [48].

Waktole et al. [34] reported that brucellosis is a disease of high economic and public health importance and has a worldwide distribution. It is also widely spread in the camel-producing horns of African countries. The seropositive animals may serve as future foci of infection, pose a public health risk, and lead to low productivity and market value of camels. Furthermore, Sprague et al. [11] have pointed out that the economic impact of brucellosis on camels can be estimated on the basis of losses due to morbidity and mortality and by estimating treatment costs.

5 Diverse brucellosis diagnostic tests experimented on camels and domestic animal species

Clinical signs of brucellosis in camels appear to be very rare [36]. Camels exposed experimentally to infection strain of *B. abortus* developed mild, transient clinical symptoms including reduced appetite, slight lameness, and bilateral lacrimation. However, orchitis and epididymitis have also been associated with brucellosis caused by *B. abortus* and *B. melitensis*. In *Brucellae* natural infections, several symptoms were observed such as retention of placenta, placentitis, uterine infections, fetal death and mummification, delayed maturity and infertility, arthritis, and hygroma. Also, abortion has been reported in pregnant camels and *B. melitensis* was isolated from aborted foetuses, genital discharge, urine, and milk [49].

In fact, herders' observations on camel illnesses are often a necessary step for veterinary scholars who are investigating aetiology, symptoms, and treatment of camel diseases [50]. Mammeri [5] emphasized that among the major constraints of camel breeding in Algeria is the lack of studies and data concerning the dominant pathologies in dromedary camel. Indeed, the great distances separating veterinary institutes and the majority of animal health research laboratories hinder a rigorous practice of research standards in microbiology, parasitology, and biochemistry, without forgetting the ambulatory, dominant character of camel herds in permanent search of pasture.

Considering the debate on the *Brucella* species concept, there is a need to describe the existing taxonomical entities of these pathogens to understand the dispersion and evolution [51]. In different geographical locations of Abu Dhabi Emirate, United Arab Emirates (UAE), a Brucellergene skin test (BST) was applied to assess its performances in camels. The BST investigated in this study proved to be a highly specific test, so authors propose using it as a confirmatory test in camels particularly when the serological tests give doubtful results on individual animals [52]. The lateral flow immunoassay (LFiA) kit, though produced specifically for cattle, is able to detect the presence of *Brucella* antibodies in camel sera [30].

The complement fixation test (CFT), the Rose Bengal test (RBT), and the serum agglutination test (SAT) have their limitations regarding sensitivity. The CFT is a mandatory test for international trade as required by the World Organization for Animal Health (OIE), but it has severe drawbacks: it is complex, time consuming, and difficult to standardize. The RBT, on the other hand, can only be applied to the monitoring of flocks in *Brucella*-free regions. The SAT is less specific than the CFT; however, it has been used in surveillance and control programmes for bovine brucellosis (OIE). The serodiagnosis of Brucellosis is additionally impaired by the allegedly strong cross-reactivity between *Brucella* spp. and *Yersinia enterocolitica O:9* and other Gram-negative bacteria [11].

According to Gwida et al. [49], best results for detecting the presence of anti *Brucella* antibodies were obtained by the fluorescence polarization assay (FPA) (79.3%), followed by the CFT (71.4%), RBT (70.7%), SAT (70.6%), and cELISA (68.8%). Therefore, the authors recommended the use of the FPA in combination with the real-time PCR in developed countries or conventional PCR with any of the commonly used serological tests in less developed countries.

Recently, Dadar et al. [2] reported that for the diagnosis of camel brucellosis, RBT ($n = 50$) and CFT ($n = 43$) were the most used tests, followed by c-ELISA ($n = 22$), bacterial culture ($n = 20$), SAT ($n = 19$), PCR-based methods ($n = 25$), MRT (Milk Ring Test) ($n = 5$), 2-ME (2-mercaptoethanol *Brucella* agglutination test) ($n = 2$), and i-ELISA ($n = 2$). Also, remarkable differences between the prevalence of camel brucellosis obtained through direct methods (15.08%) and indirect methods (8.49%) have been shown.

Table 1 shows several examples of *Brucella* spp. isolated using several techniques from *C. dromedarius* and other domestic animals species, which may be in promiscuity with camels.

Table 2 shows some examples of *Brucella* spp. in wild animals being likely in promiscuity with dromedary camel.

6 Brucellosis prophylaxis measures and eradication challenges

Dadar et al. [2] stipulated that field data are sparse and often lack validation, while vaccine safety and efficacy have not been studied experimentally. Currently, there is no vaccine registered for use in camels, and thus vaccination is not recommended by the OIE.

Mammeri [18,20] reported that in developing countries, prophylaxis should focus on vulgarization of populations at risk using vernacular and local languages through mass-media means (TV, radio, and journals) targeting in first; standing the nomadic populations and highlight the importance of the full respect of brucellosis treatment periods in humans, scholastic sanitary education through demonstrative posters. These procedures

Table 1: Examples of domestic animals' infections linked to zoonotic human brucellosis cases, isolated *Brucella* spp., used diagnostic tests, and concerned countries

Animal species	*Brucella* spp.	Country	Diagnostic tests	References
Dromedary camel (*C. dromedarius*)	*B. melitensis*	Egypt	AMOS-PCR	[53]
	B. melitensis *B. abortus*	Qatar	Blood culture Serology	[54]
	B. melitensis *B. abortus*	Iran	PCR Blood culture Serology	[55]
	Brucella spp.	UAE	c-ELISA BST	[52]
Cattle (*Bos taurus*)	*B. abortus:* biovar1, biovar3, biovar6 *B. melitensis:* biovar3	Italy	Blood culture AMOS PCR PCR-RFLP	[56]
	B. abortus: biovar3	Tanzania	Blood culture, qPCR, MLVA-VNTR genotyping	[57]
	B. abortus: biovar1, biovar3 *B. melitensis:* biovar3	Algeria	Specimen culture Multiplex PCR-AMOS ERY PCR-MLVA genotyping	[58]
Sheep (*Ovis aries*)	*B. abortus:* biovar1, biovar3 *B. melitensis:* biovar3 *B. ovis*	Italy	Blood culture AMOS PCR PCR-RFLP	[56]
Goat (*Capra aegagrus hircus*)	*B. abortus:* biovar3 *B. melitensis:* biovar1 biovar3	Italy	Blood culture AMOS PCR PCR-RFLP	[56]
Dog (*Canis lupus familiaris*)	*B. abortus*	Pakistan	SAT ELISA qPCR	[28]
Cat (*Felis catus*)	*B. melitensis*	Greece	16S metagenomics technique qPCR	[26]
Horse (*Equus caballus*)	*B. abortus:* biovar1	Italy	Blood culture AMOS PCR PCR-RFLP	[56]

AMOS: (abortus, melitensis, ovis, suis); BST: Brucellergene skin test; ELISA: enzyme-linked immunosorbent assay; MLVA-VNTR: multiple loci variable number of tandem repeats analysis; PCR: polymerase chain reaction; qPCR: quantitative PCR; RBPT: Rose Bengal plate agglutination test; RFLP: restriction fragment length polymorphism techniques; TAT: tube agglutination test.

seem to be the most efficient and enduring solutions to fight brucellosis in humans, especially in the case of lack of rapid efficient diagnostic tools. Also, Mammeri [18] recommended that veterinarians should be made aware on the importance of their role in the detection of zoonoses and vulgarization of both breeders and consumers, while insisting on ensuring their personal safety when handling animals, biological samples, or vaccines.

In some regions of the Algerian Sahara, pasteurized camel milk has recorded success, even though it has reached exorbitant prices [44]. While in the steppe regions of Algeria, the camel periurban breeding mode and the resulting commercial model which is relatively innovative and tends to shorten the distribution circuits by eliminating the intermediary actors; however, it would not be free of risks for the consumer [4–6]. For the camel periurban breeding system, Mammeri [4–6] recommended that the promotion of she-camel milk must necessarily be accompanied by health security, hygiene, and traceability procedures, especially since a large part of consumers is convinced that camel milk constitutes a new therapeutic alternative against diseases resistant to conventional treatments.

Consequently, it is necessary to consume pasteurized she-camel milk, as it is the case in some regions of North Africa [44]. Pasteurization or proper boiling of milk is adequate to prevent transmissions of diseases especially brucellosis through milk [23].

Furthermore, a strategic plan should be developed for decreasing the chance of contact of animals at different situations and to keep only a few healthy and fertile camels per herd together, with immunization campaigns and public health education. Modern animal husbandry practices and management, in addition to disease prevention techniques should be introduced continuously [13].

Table 2: Major wild animals species which may be in promiscuity with dromedary camels, isolated *Brucella* spp., used diagnostic tests, and concerned countries

Animal species	*Brucella* spp.	Country	Diagnostic tests	References
Spotted hyena (*Crocuta crocuta*)	*B. abortus*	Several countries	Culture PCR/sequencing	[38]
Golden jackal (*Canis aureus*)	*B. abortus*	Serbia	qPCR	
Coyote (*Canis latrans*)	*B. abortus*	Several countries	Culture PCR/sequencing	
Wolf (*Canis lupus*)	*B. abortus*	Several countries	Culture PCR/sequencing	
Black-backed jackal (*Canis mesomelas*)	*B. abortus*	Several countries	Culture PCR/sequencing TAT	
Several fox species	*B. abortus*	Several countries	Culture PCR/sequencing	
Wild Boar (*Sus scrofa*)	*B. melitensis:* biovar3 *B. suis:* biovar2	Italy	AMOS-PCR PCR-RFLP	[56]
Rodent Sprague Dawley Rats	*B. abortus* biotype 1	Bangladesh	RBPT TAT ELISA AMOS-PCR	[39]
Bats (*Miniopterus schreibersii, Myotis Blythii*)	*Brucella* DNA	Georgia	qPCR Conventional PCR	[40]

AMOS: (abortus, melitensis, ovis, suis); ELISA: enzyme-linked immunosorbent assay; PCR: polymerase chain reaction; qPCR: quantitative PCR; RBPT: Rose Bengal plate agglutination test; RFLP: restriction fragment length polymorphism techniques; TAT: tube agglutination test.

Brucellosis should be controlled by vaccination of camels and primary hosts (cattle and small ruminants), improving hygiene and reducing the chances of contact between infected and non-infected animals, although it would not be easy under many pastoral circumstances, where resources are lacking and the movement of livestock is difficult to restrict [48]. Mammeri et al. [59] recommended the improvement of the livestock census system to obtain more accurate data on abortive females, in addition to the implementation of a reliable and easily practised system of animal identification to ensure epidemiological control. Both sexes of infected camels act as disease transmitters, public health nuisance, and need to be identified to eliminate the spread of the disease [23].

Since camels suffer from lack of attention and negligence in numerous countries, the control of brucellosis in camels is severely hampered [11]. Additionally, Mammeri [5] stipulates the fact that the school educational level of nomadic camel herders is generally poor, which would make more difficult the tasks of vulgarization and improvement of the breeding technical skills. According to Sprague et al. [11], several approaches could be applied to improve the situation and significantly reduce the occurrence of brucellosis in camels, which include encouragement of closer interaction between animal keepers and veterinary personnel. Mammeri [18] suggests the minimizing of brucellosis zoonotic risks in developing countries by upgrading the quality of ruminants' supervision, following a strict policy of animal testing-and-slaughtering to eradicate brucellosis in livestock, and the use of diagnostic tools with high precision such as PCR and ELISA. In addition, surveillance and control programmes of brucellosis have to include eradication of the disease in dogs, cats, and companion animals [32].

Since the risk factors influencing the seroprevalence of camel brucellosis at the animal level are district, herd size, and contact with ruminants, there is a need for further studies investigating brucellosis in ruminants and testing the correlation between brucellosis in camels and in ruminants [60]. The widespread occurrence of co-infection in domestic ruminants with abortifacient pathogens [21,61] would make differential diagnosis more difficult for veterinarians, thus, requiring more caution before deciding about vaccination with *Rev 1* [18].

The diagnosis of brucellosis when it is endemic in a country is challenging due to the various clinical presentations and leads to labour loss due to serious complications; thus, it should be considered in the differential diagnosis of numerous diseases [62]. Moreover, among diagnostic and eradication challenges, the weak humoral response elicited against *Brucella* infection may explain the failure of serological tests. Since *Brucellae* are facultative intracellular organisms, fluctuations in the antibody titers in the presence or absence of bacteremia could also be an explanation. PCR may be an indispensable tool for identification of such animals [63]. During a study conducted by Mammeri [17,20] about therapeutic approaches of rural and urban physicians to confront human brucellosis in the governorate of Biskra (Algeria), results showed that period of antibiotherapy goes from 10 days to 1 year; percentage of relapse to brucellosis after treatment was 10–30% according to 56.33% of the responders, also rural physicians were well-informed about brucellosis symptoms than urban physicians.

One Health approach may establish a guarantee for controlling infections in dogs as well as in humans since it places more focus on environmental issues, via control of stray dogs and finding out more about habitats, conservation, and management of wild *Canidae* whenever possible. The infection occurrence, however, can be decreased by taking all the measures from primary to tertiary preventions and ensuring the euthanasia, isolation, or removal (in some cases) of infected dogs in both developing and developed countries [64].

Consequently, screening animals for brucellosis in villages and slaughterhouses is necessary and that further attempts should be made to control this disease. RBPT and ELISA can be used for the screening of brucellosis in animal and human populations, but ELISA is more sensitive. RBPT can be used for primary screening of brucellosis cases because cross reactivity is present in the RBPT antigen and confirmation must be made with a specific serological test, such as *B. abortus*-specific ELISA [65].

7 Conclusions

The complex ecological and emblematic positions, of the dromedary camel, seem to make it an inescapable reservoir of contagious diseases, especially that it puts itself incidentally in first line of contact with the wild fauna, compared to the other domestic species. Furthermore, the difficulty or even the impossibility of the detection and the control of the major transmissible diseases in the wild animals, especially in developing countries, prevent an efficient and continuous epidemiological surveillance of possible interferences between wild animals that may occur in the same territories of dromedary camel, particularly in the vast steppe and desert rangelands in Africa.

Camel brucellosis zoonotic threats are mainly related to the consumption of raw she-camel milk traditions, as well as to the clumsy culinary habits of the population living in a nomadic way. In this context, extension and rapprochement between agricultural vulgarization agents and camel herders seem to be the most effective remedy.

The path towards a total eradication of animal and human brucellosis, especially in developing countries, seems to be delicate and confused, especially with the difficulty of systematically applying quarantine periods for all newly introduced or suspected animals, the lack of reliable diagnostic means, in addition to the impossibility of applying a rigorous control at the level of common grazing areas, livestock markets, and border areas, where veterinarians should have more initiative.

Funding information: The author states no funding involved.

Conflict of interest: The author states no conflict of interest.

Data availability statement: Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

References

[1] Omer M, Megersa B, Abebe R, Abera M, Regassa A, Abdrehman Y, et al. Seroprevalence of brucellosis in camels in and around Dire Dawa City, Eastern Ethiopia. J Anim Vet Adv. 2011;10:1177–83. doi: 10.3923/javaa.2011.1177.1183.
[2] Dadar M, Omar SS, Shahali Y, Fakhri Y, Godfroid J, Khaneghah AM. The prevalence of camel brucellosis and associated risk factors: a global meta-epidemiological study. Qual Assur Saf Crop Foods. 2022;14(3):55–93. doi: 10.15586/qas.v14i3.1088. Accessed 09.08.22.
[3] Omer MM, Musa MT, Bakhiet MR, Perrett L. Brucellosis in camels, cattle and humans: associations and evaluation of serological tests used for diagnosis of the disease in certain nomadic localities in Sudan. Rev sci tech int Epiz. 2010;29(3):663–9. doi: 10.20506/rst.29.3.2003.
[4] Mammeri A. Periurban circuits of she-camel milk sales in Algeria: the case of wilaya of Biskra. Renc Rech Rumin. 2016a; 23:93 (article in French).
[5] Mammeri A. Contribution to the study of dominant pathologies risk factors in dairy farming of the Governorates of Biskra and Constantine. PhD thesis; Algeria: University of Constantine 1; 2016b. p. 259 (thesis in French).
[6] Mammeri A, Khir A. Survey on health and therapeutic virtues of she-camel milk among customers and staffs of she-camel milk dairies in the region of M'Sila. Algeria Renc Rech Rumin. 2018;24:383 (article in French).
[7] Maymona AM, Shigidy MT, Al juboori AY. Sero-prevalence and Epidemiology of Brucellosis in Camels, Sheep and Goats in Abu Dhabi Emirate.Intern. J Anim Vet Adv. 2013;5(2):82–6.
[8] Wernery U. Camelid brucellosis: A review. Rev Sci Tech int Epiz. 2014;33(3):839–57. doi: 10.20506/rst.33.3.2322.

[9] Wu G, Yang C, Li j, Liu N, Yao W, Zhang R, et al. Prevalence study of brucellosis among high-risk people in Xinjiang region, China. Microbiol Discovery. 2013;1(2):1–5. doi: 10.7243/2052-6180-1-2.

[10] Godfroid J, Scholz HC, Barbier T, Nicolas C, Wattiau P, Fretin D, et al. Brucellosis at the animal ecosystem human interface at the beginning of the 21st century. Prev Vet Med. 2011;102(2):118–31. doi: 10.1016/j.prevetmed.2011.04.007.

[11] Sprague LD, Al-Dahouk S, Neubauer H. A review on camel brucellosis: A zoonosis sustained by ignorance and indifference. Pathog Glob Health. 2012;106(3):144–9. doi: 10.1179/2047773212Y.0000000020.

[12] Gwida M, Al Dahouk S, Melzer F, Rösler U, Neubauer H, Tomaso H. Brucellosis-regionally emerging zoonotic disease? Croat Med J. 2010;51(4):289–95. doi: 10.3325/cmj.2010.51.289.

[13] Hadush A, Pal M, Kassa T, Zeru F. Sero-epidemiology of camel brucellosis in the Afar region of Northeast Ethiopia. J Vet Med Anim Health. 2013;5(9):269–75. doi: 10.5897/JVMAH 13.0235.

[14] Seifert SH. Tropical animal health. 2nd edn. Dordrecht: Dordrecht Kluwer Academic Publishers; 1996.

[15] Miguel E, El Idrissi A, Chevalier V, Caron A, Faye B, Peiris M, et al. (FAO) Ecological and epidemiological roles of camels: Lessons from existing and emerging viral infections. EMPRES-Animal Health. 2016;360(46):4–8.

[16] Zhu S, Zimmerman D, Deem SLA. Review of zoonotic pathogens of dromedary camels. Eco Health. 2019;16:356–77. doi: 10.1007/s10393-019-01413-7.

[17] Mammeri A. Contribution to the identification of brucellosis persistence factors in the region of Biskra. National High Veterinary School of Algiers (Algeria). MVsc thesis; Algeria: High veterinary school of Algiers; 2011. p. 259 (dissertation in French).

[18] Mammeri A. Persistence factors of brucellosis in Humans and animals: Priority of vulgarization and sanitary education in developing countries (Review article). J Anim Sci Adv. 2015;5(10):1422–9.

[19] Mammeri A, Alloui N. Investigation on the psycho-pathological influence of brucellosis on private veterinary practitioners in the region of Biskra. 5th International Days of Veterinary Medicine of the Department of Veterinary Sciences. PADESCA Laboratory, Constantine 1 University; 2012. p. 15–6 (communication in French).

[20] Mammeri A. Survey on therapeutic protocols of Human brucellosis prescribed by urban and rural physicians and persistence risk factors in the Governorate of Biskra. Algeria J Pharm Chem Biol Sci. 2018;5(4):437–48. https://www.jpcbs.info/2017_5_4_19_%20Mammeri.pdf/Accessed 18.05.19.

[21] Zemmouri L, Besbaci M, Mammeri A, Lafri M. Sero-epidemiological investigation of the major abortive bacterial agents in ewes of M'Sila Governorate, Algeria. Bull UASVM Vet Med. 2020;77(2):24–33. doi: 10.15835/buasvmcn-vm:2020.0004.

[22] Agrawal RP, Beniwal R, Charma RC, Kochar DK, Tuteja FC, Ghouri SK, et al. Effect of raw camel milk in type 1 diabetic patients: 1 year randomized study. J Camel Pract Res. 2005b;12(1):27–35.

[23] Rajeswari S, Gupta VK, Bhardwaj B, Shome BR, Nagalingam M, Rahman H. A report of seroprevalence of camel brucellosis in India. J Camel Pract Res. 2013;20(2):183–6.

[24] Baek BK, Lim CW, Rahman MS, Kim CH, Oluoch A, Kakoma I. Brucella abortus infection in indigenous Korean dogs. Can J Vet Res. 2003;67(4):312–4. PMID: 14620870. PMCID: PMC280718.

[25] Anonymous. CFSPH. Center of Food Security and Public Health, IOWA State University; 2009. https://www.cfsph.iastate.edu/DiseaseInfo/notes/Brucellosis_Bmelitensis.pdf.

[26] Dougas G, Tsakris A, Beleri S, Patsoula E, Billinis C, Papaparaskevas J. Evidence of *Brucella melitensis* DNA in the Microbiome of *Ctenocephalides felis* from Pet Cats in Greece. Vector-Borne Zoonotic Dis. 2020;20(5):390–2. doi: 10.1089/vbz.2019.2510.

[27] Wareth G, Melzer F, El-Diasty M, Schmoock G, Elbauomy E, Abdel-Hamid N, et al. Isolation of *Brucella abortus* from a dog and a cat confirms their biological role in re-emergence and dissemination of bovine brucellosis on dairy farms. Transbound Emerg Dis. 2017;64(5):27–30. doi: 10.1111/tbed.12535.

[28] Jamil T, Melzer F, Khan I, Iqbal M, Saqib M, Hammad Hussain M, et al. Serological and molecular investigation of *Brucella* species in dogs in Pakistan. Pathogens. 2019;8(4):294. doi: 10.3390/pathogens8040294.

[29] Coelho AC, Díez JG, Coelho AM. Risk factors for Brucella spp. in domestic and wild animals. In: Baddour MM, editor. Book: Brucellosis. Chapter 1: Risk factors for Brucella spp. in domestic and wild animals. London, UK: IntechOpen Book Series, 2015. doi: 10.5772/61325.Accessed 01.03.20.

[30] Madu GA, Adama OR, James BW, Hassan M, Lubabatu I, Esther M, et al. Sero-prevalence of camel brucellosis in three abattoirs of Northern Nigeria. J Vet Med Anim Health. 2016;8(3):15–20. doi: 10.5897/JVMAH2015.0380.

[31] Ullah S, Jamil T, Mushtaq MH, Saleem MH. Prevalence of brucellosis among camels in District Muzaffargarh, Pakistan. J Inf Mol Biol. 2015;3(2):52–6. doi: 10.14737/journal.jimb/2015/3.2.52.56.Accessed 09.08.22.

[32] Hernández-Mora G, Palacios-Alfaro JD, González-Barrientos R. Wildlife reservoirs of brucellosis: *Brucella* in aquatic environments. Rev Sci Tech Int Epiz. 2013;32(1):89–103. doi: 10.20506/rst.32.1.2194.

[33] Benfodil K, Mohamed Cherif A, Ansel S, Fettata S, Bounar-Kechih S, Ait-Oudhia K. Seroprevalence and associated risk factors for camel brucellosis in south Algeria. Veterinaria. 2022;71:17–26. doi: 10.51607/22331360.2022.71.1.17. Accessed 09.08.22.

[34] Waktole H, Aden M, Ashenaf H. Seroepidemiology of camel brucellosis in and around Dire Dawa, Eastern Ethiopia. Vet Med Int. 2022;16:6624293. doi: 10.1155/2022/6624293 Accessed 09.08.22.

[35] ANSES. Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail.Fiche de description de danger biologique transmissible par les aliments/Brucella spp; 2014. p. 3 (article in French). https://www.anses.fr/fr/content/fiche-de-description-de-danger-biologique-transmissible-par-les-aliments-brucella-spp.

[36] Bertelloni F, Mazzei M, Cilia G, Forzan M, Felicioli A, Sagona S, et al. Serological survey on bacterial and viral pathogens in wild boars hunted in Tuscany. Ecohealth. 2020;17(1):85–93. doi: 10.1007/s10393-020-01475-y.

[37] ENVF (Ecoles Nationales Vétérinaires Françaises). Maladies Règlementées.La brucellose animale. Polycopié rédigé de manière concertée par les enseignants des Ecoles Nationales Vétérinaires Françaises. Rédaction et sa mise à jour par Professeur Jean-Pierre Ganière (ONIRIS); 2019 (article in French). https://eve.vet-alfort.fr/mod/resource/view.php? id=44926.

[38] Kosoy M, Goodrich I. Comparative ecology of *Bartonella* and *Brucella* infections in wild carnivores. Front Vet Sci. 2019;5:322. doi: 10.3389/fvets.2018.00322.

[39] Islam MA, Khatun MM, Baek BK. Rats born to Brucella abortus infected mothers become latent carriers of Brucella. J Infect Dev Ctries. 2012;6(3):256–61. doi: 10.3855/jidc.1997.
[40] Bai Y, Urushadze L, Osikowicz L, McKee C, Kuzmin I, Kandaurov A, et al. Molecular survey of bacterial zoonotic agents in bats from the country of Georgia (Caucasus). PLoS One. 2017;12(1):e0171175. doi: 10.1371/journal.pone.0171175.
[41] Radwan AI, Bekairi SI, Mukayel AA, Al-Bokmy AM, Prasad PV, Azar FN, et al. Control of Brucella melitensis infection in a large camel herd in Saudi Arabia using antibiotherapy and vaccination with Rev. 1 vaccine. Rev Sci Tech. 1995;14:719–32. doi: 10.20506/rst.14.3.860.
[42] Fosgate GT, Carpenter TE, Chomel BB, Case JT, DeBess EE, Reilly KF. Time-space clustering of human brucellosis, California, 1973–1992. Emerg Infect Dis. 2002;8(7):672–8. doi: 10.3201/eid0807.010351.
[43] Osoro EM, Munyua P, Omulo S, Ogola E, Ade F, Mbatha P, et al. Strong association between human and animal brucella seropositivity in a linked study in Kenya, 2012–2013. Am J Trop Med Hyg. 2015;93(2):224–31. doi: 10.4269/ajtmh.15-0113.
[44] Faye B, Jaouad M, Bhrawi K, Senoussi A, Bengoumi M. Camel farming in North Africa: Current state and prospects. Rev d'élevage et de Méd Vét des Pays Tropicaux. 2015;67(4):213–21. doi: 10.19182/remvt.20563 (article in French with abstract in English).
[45] Gossner C, Danielson N, Gervelmeyer A, Berthe F, Faye B, Kaasik Aaslav K, et al. Human-dromedary camel interactions and the risk of acquiring zoonotic middle east respiratory syndrome coronavirus infection. Zoonoses Public Health. 2016;63(1):1–9. doi: 10.1111/zph.12171.
[46] Wanjohi M, Gitao CG, Bebora L. The prevalence of brucella *spp* in camel milk marketed from Northeastern province. Res Op Anim Vet Sci. 2012;2(7):425–34.
[47] Breedlove B. Veiled dangers in an idyllic setting. Emerg Infect Dis. 2020;26(2):395–6. doi: 10.3201/eid2602.AC2602.
[48] Harrison S, Kivuti-Bitok L, Macmillan A, Priest P. EcoHealth and one health: A theory-focused review in response to calls for convergence. Environ Int. 2019;132:104837. doi: 10.1016/j.envint.2019.05.031.
[49] Gwida M, El-Gohary A, Melzer F, Khan I, Rösler U, Neubauer H. Brucellosis in camels. Res Vet Sci. 2012;92(3):351–5. doi: 10.1016/j.rvsc.2011.05.002.
[50] Volpato G, Lamin Saleh SM, Di Nardo A. Ethnoveterinary of Sahrawi pastoralists of Western Sahara: Camel diseases and Remedies. J Ethnobiol Ethnomed. 2015;11:54. doi: 10.1186/s13002-015-0040-4.
[51] Guzmán-Verri C, Suárez-Esquivel M, Ruíz-Villalobos N, Zygmunt MS, Gonnet M, Campos E, et al. Genetic and phenotypic characterization of the etiological agent of canine orchiepididymitis smooth *Brucella* sp.BCCN84.3. Front Vet Sci. 2019;6:175. doi: 10.3389/fvets.2019.00175.
[52] Khalafalla AI, Rashid J, Khan RA, Alamin KM, Benkhelil A, De Massis F, et al. Preliminary comparative assessment of brucellergene skin test for diagnosis of brucellosis in dromedary camels (*Camelus dromedarius*). Vector Borne Zoonotic Dis. 2020 Jun;20(6):412–7. doi: 10.1089/vbz.2019.2537.
[53] Abdelgawad HA, Sultan S, Aml Mokhtar MAA, Abd Al-Azeem MW. Serological and molecular detection of Brucella species in camel. Benha Vet Med J. 2017;33(1):314–9. http://www.bvmj.bu.edu.eg.
[54] Garcell HG, Garcia EG, Pueyo PV, Martín IR, Arias AV, Alfonso Serrano RN. Outbreaks of brucellosis related to the consumption of unpasteurized camel milk. J Infect Public Health. 2016;9(4):523–7. doi: 10.1016/j.jiph.2015.12.006. Epub 2016 Jan 12. PMID: 26796768.
[55] Khamesipour F, Rahimi E, Shakerian A, Doosti A, Momtaz H. Molecular study of the prevalence of *Brucella abortus* and *Brucella melitensis* in the blood and lymph node samples of slaughtered camels by Polymerase Chain Reaction (Pcr) in Iran. Acta Veterinaria-Beograd. 2014;64(2):245–56. doi: 10.2478/acve-2014-0023.
[56] De Massis F, Zilli K, Di Donato G, Nuvoloni R, Pelini S, Sacchini L, et al. Distribution of Brucella field strains isolated from livestock, wildlife populations, and humans in Italy from 2007 to 2015. PLoS One. 2019;14(3):e0213689. doi: 10.1371/journal.pone.0213689.
[57] Mathew C, Stokstad M, Johansen TB, Klevar S, Mdegela RH, Mwamengele G, et al. First isolation, identification, phenotypic and genotypic characterization of *Brucella abortus biovar 3* from dairy cattle in Tanzania. BMC Vet Res. 2015;11:156. doi: 10.1186/s12917-015-0476-8.
[58] Khames M, Mick V, Jesús de Miguel M, Girault G, Conde-Álvarez R, Khelef D, et al. The characterization of Brucella strains isolated from cattle in Algeria reveals the existence of a B. abortus lineage distinct from European and Sub-Saharan Africa strains. Vet Microbiol. 2017;211:124–8. Accessed 12.05.2019. https://www.researchgate.net/publication/320421034_The_characterization_of_Brucella_strains_isolated_from_cattle_in_Algeria_reveals_the_existence_of_a_B_abortus_lineage_distinct_from_European_and_Sub-Saharan_Africa_strains.
[59] Mammeri A, Alloui MN, Kayoueche FZ, Benmakhlouf A. Epidemiological survey on abortions in domestic ruminants in the governorate of Biskra, eastern arid region of Algeria. J Anim Sci Adv. 2013;3(8):403–15.
[60] Mohamud AS, Kothowa JP, Mfune RL, Mubanga M, Godfroid J, Muma JB. Seroprevalence and risk factors associated with Brucella Infection in camels in the Puntland State of Somalia. Vet Sci. 2021;8:137. doi: 10.3390/vetsci8070137.
[61] Nasiri A, Ashraf M, Shakoor A, Adil M, Abbas T, Kashif M, et al. Co-infection of water buffaloes in Punjab, Pakistan, with *Neospora caninum* and *Brucella abortus*. Turk J Vet Anim Sci. 2014;38:572–6. doi: 10.3906/vet-1310-36. © TÜBİTAK.
[62] Çalik S, Gökengin AD. Human brucellosis in Turkey: A review of the literature between 1990 and 2009. Turk J Med Sci. 2011;41(3):549–55. doi: 10.3906/sag-0911-404. © TÜBİTAK.
[63] Raies Ul Islam M, Pratap Gupta M, Kaur Sidhu P, Filia G, Mohan Saxena H, Ahmed Shafi T. Comparative evaluation of indirect enzyme linked immunosorbent assay, Rose Bengal plate test, microagglutination test, and polymerase chain reaction for diagnosis of brucellosis in buffaloes. Turk J Vet Anim Sci. 2013;37:306–10. doi: 10.3906/vet-1201-39. © TÜBİTAK.
[64] Uçan US. Canine brucellosis in Turkey from an environmental perspective. Turk J Vet Anim Sci. 2016;40:131–6. doi: 10.3906/vet-1510-35. © TÜBİTAK.
[65] Hussain I, Arshad MI, Mahmood MS, Akhtar M. Seroprevalence of brucellosis in Human, cattle, and Buffalo populations in Pakistan. Turk J Vet Anim Sci. 2008;32(4):315–8, https://journals.tubitak.gov.tr/veterinary/vol32/iss4/14.