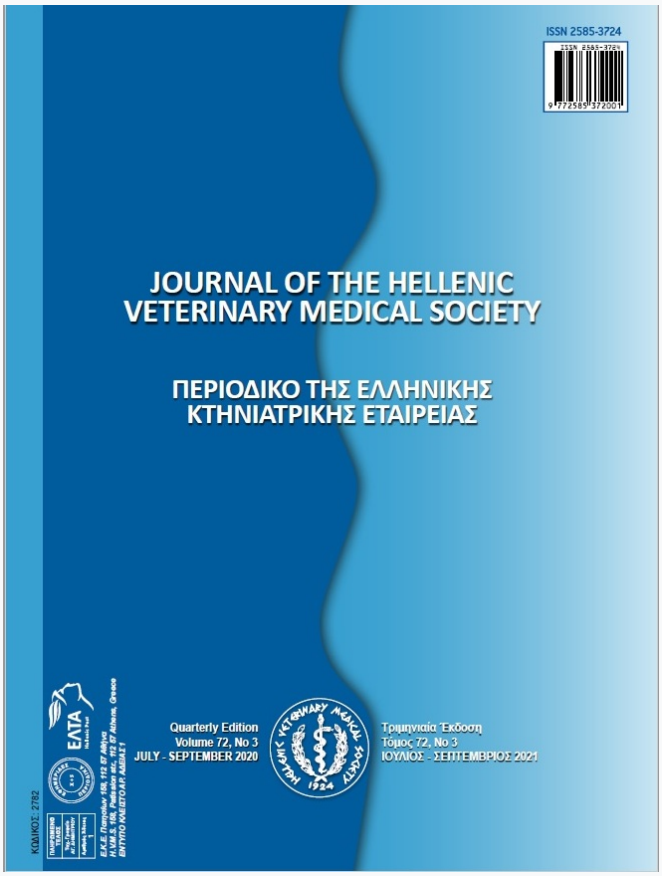
Journal of the Hellenic Veterinary Medical Society

Vol 72, No 3 (2021)



Epidemiosurveillance of Brucella infection in humans, non-ruminants and wildlife from Pakistan perspective (2000-2020)

M ZEESHAN AKRAM, A ULLAH KHAN, B SHAUKAT ALI, S SHAHID, A BATOOL

doi: 10.12681/jhvms.28501

To cite this article:

ZEESHAN AKRAM, M., ULLAH KHAN, A., SHAUKAT ALI, B., SHAHID, S., & BATOOL, A. (2021). Epidemiosurveillance of Brucella infection in humans, non-ruminants and wildlife from Pakistan perspective (2000-2020). *Journal of the Hellenic Veterinary Medical Society*, *72*(3), 3117–3126. https://doi.org/10.12681/jhvms.28501

J HELLENIC VET MED SOC 2021, 72(3): 3117-3126
ΠΕΚΕ 2021, 72(3): 3117-3126

Research article
Ερευνητικό άρθρο

Epidemiosurveillance of *Brucella* infection in humans, non-ruminants and wildlife from Pakistan perspective (2000-2020)

M. Zeeshan Akram[a,*], A. Ullah Khan[b], B. Shaukat Ali[c], S. Shahid[d], A. Batool[d]

[a] *Faculty of Bioscience Engineering, Department of Biosystems, Katholieke Universiteit, Leuven, Belgium*

[b] *Friedrich-Loeffler-Institut, Jena-Germany*

[c] *Faculty of Sciences, Department of Agricultural and Environmental Sciences University of Southern Queensland , Toowoomba, Australia*

[d] *Department of Microbiology, University of Veterinary and Animal Sciences, Lahore 54000, Pakistan*

ABSTRACT: This review aimed at providing an overview of the prevalence and epidemiosurveillance of brucellosis in non-ruminants and humans in Pakistan during 2000-2020. Sero-prevalence of brucellosis has been reported in non-ruminants such as camels, equines, dogs and humans with the range of 0.5-21%, 16.23-62.6%, 9.2-63.8% and 2.0-70% respectively. Non-target species like Avian, reptiles and amphibians were also reported with the prevalence of 2.5%, 24.9% and 25% respectively. Ignorance and indifference make it endemic in ruminants and much-neglected disease in non-ruminants with less or no studies reported in canines. Vaccines are available and being used for ruminants while none is available for non-ruminants, which may serve as an important source of spreading disease in animals and humans. In Pakistan, it is considered as ignored disease in non-ruminants lacking effective policies for control and eradication. This review guides policymakers to draw guidelines regarding brucellosis control and eradication using one health approach.

Keywords: Brucellosis; non-ruminants; endemic; zoonosis; epidemiology; Pakistan

Corresponding Author:
Muhammad Zeeshan Akram, Faculty of Bioscience Engineering, Department of Biosystems, Katholieke Universiteit, Leuven, Belgium
E-mail address: zeeshanakram219@gmail.com

Date of initial submission: 21-04-2020
Date of revised submission: 12-02-2021
Date of acceptance: 20-04-2021

INTRODUCTION

Brucellosis is a zoonotic disease affecting both animals and humans caused by bacteria of the genus *Brucella* (Karthik et al., 2016). This contagious disease poses a heavy economic impact on the livestock industry and also has serious health hazards. *Brucella* is a facultative intracellular, non-motile, non-spore-forming coccobacillus (Shahzad et al., 2017). *B. melitensis*, *B. abortus*, and *B. suis* cause abortion and infertility in domestic animals, while *B. canis* causes infection in canines (Lopes et al., 2010; Godfroid and KaÈsbohrer, 2002; Karthik et al., 2016). Camel is considered susceptible to *B. abortus* and *B. melitensis* (Shahzad et al., 2017). Humans can be infected by *B. melitensis, B. abortus, B. suisbiovars 1-4* and *B. canis*making it a public health concern. *B. melitensis*is considered the most pathogenic and invasive species for humans followed by *B. abortus, B. suis*and *B. canis* in descending order (Lopes et al., 2010). *Brucella* species and their potential to infect humans are presented in Table 1.

Infected domestic animals are the main source of infection as well as the natural reservoir of these bacteria. They are excreted in milk, urine, semen and fetal fluids of the infected animals and transmitted through the conjunctiva, oral, nasal and sexual routes (Alfattli, 2016). The practice of rearing mixed livestock species can facilitate the spread of the disease (Radostitis et al., 2007). Humans are most frequently infected via direct contact with infected reproductive material, through inspecting and whipping slaughtered animals and consuming rawmilk (Earhart et al., 2009; Liu et al., 2014). Person-to-person transmission is very rare. Breastfeeding, blood transfusion, organ transplantation, and accidental self-inoculation of *Brucella* vaccine strains can result to disease in humans.

Brucella is a facultative intracellular microorganism, which multiplies and escapes the host immune mechanism simultaneously by developing inside phagocytic cells (Gorvel and Moreno, 2002). Maintaining the chronic infection by this pathogen lies in its ability to survive and replicate within the macrophages (Neta et al., 2010; Roop et al., 2004).

The disease is of great economic importance having the potential effects on the production and reproductive status of animals including infertility and cessation of milk production after abortion (Wadood et al., 2009). In animals, the main clinical signs are abortion, low milk production, infertility, weak offsprings and death due to acute metritis and retained fetal membranes.The clinical signs of brucellosis in camels can vary from asymptomatic to abortion. Retention of fetal membranes, infertility, and delayed sexual maturity have been documented. Males may suffer from orchitis and arthritis accompanied by acute lameness (Sprague et al., 2012). In equines, the clinical manifestations of brucellosis are poll-evil and fistulous withers due to the inflammation of supraspinous bursa and connective tissue, leading to abscess formation and fistulation in the affected regions.

Table 1: Currently described Brucella species and their zoonotic potential (Sprague et al., 2012)

Species	Biovars	Animal host	Human disease
Brucella (B.) abortus	1-9	Cattle, bison, buffalo, elk, yak, camel	Yes
B. melitensis	1-3	Sheep, goat, cow, camel	Yes
	3	Nile catfish; dog	
B. suis	1	Horse	Yes (biovars 1-4)
	1,2,3	Pig, wild boar	
	2	European hare	
	4 (B. rangiferi)	Caribou, reindeer	
	5	Rodents	Yes
B. ovis		Ram	Not reported
B. neotomae		Rodent	Not reported
B. canis		Canines	Yes (rarely)
B. ceti		Whale, dolphin, porpoise	Yes
B. pinnipedialis		Seal	Not reported
B. microti		Common vole, red fox; (soil)	Not reported
B. inopinata		Human	Yes
Baboon isolate		Baboon	Not reported
BO2		Unknown	Yes
Australian rodent strains		Rodents	Yes

Occasionally abortions and other reproductive problems are also reported (Megid et al., 2010).The typical sign in female dogs is late abortion followed by a mucoid, serosanguineous, brownish, or gray vaginal discharge that persists for up to six weeks (Hollett, 2006; Shin and Carmichael, 1999). The clinical signs in males are severe epididymitis, orchitis, and prostatitis (Hollett, 2006; Wanke, 2004). Natural infections of birds with *Brucella* and transmissions of disease from aborting cows to birds were discussed many times in the literature (Shahzad et al., 2018; Wareth et al., 2020). However, birds often show no clinical signs but they do occur, symptoms frequently include enteritis and diarrhea (Wareth et al., 2020). In the case of amphibians, pathologic changes ranging from individual, localized disease manifestations (e.g. subcutaneous abscess, skin lesions, swollen paravertebral ganglia, panopthalmitis) to systemic bacterial infections with high mortality were observed (Mühldorfer et al., 2017). The clinical manifestation of brucellosis in humans is an undulant fever in which the temperature can vary from 37ºC in the morning to 40ºC in the afternoon. Other symptoms like night sweats, chills and weakness are also reported. Malaise, insomnia, anorexia, headache, arthralgia, constipation, sexual impotence, nervousness, and depression are also common in patients (Megid et al., 2010).

The gold standard test for diagnosis of brucellosis is isolation and identification of the organism. It takes a longer time, which makes this method laborious and time-consuming. Infection risk is a major hurdle in culturing *Brucella* due to its zoonotic potential (Karthik et al., 2014). A presumptive diagnosis can be made by a different serological test like Rose Bengal Plate Test (RBPT), Serum Agglutination Test (SAT) and Enzyme-Linked immune sorbent assay (ELISA) (Nicoletti, 2007). Other screening tests include Buffered Plate Agglutination Test (BPAT), Milk Ring Test (MRT), Complement Fixation Test (CFT), and Fluorescence Polarization Test (FPT) (Acha and Szyfres, 2003; Godfroid *et al.,* 2010). The use of PCR to identify the *Brucella* species up to biovars level has increased the efficiency of the test. It is an easy, cost-effective and less time-consuming method to identify the organism (Fernando et al., 2010).

Expansion of the animal industry, lack of hygienic conditions on the farm and improper food processing makes brucellosis a public health risk. It spreads from one region to others due to international travel, importation of animals and their derived products. Being a zoonotic disease, it is considered an occupational hazard for those persons having direct contact with infected animals like farmers, veterinarians, and butchers (Dil et al., 2017). Brucellosis has been eradicated from many developed countries but still endemic in Africa, the Middle East, the Mediterranean, Asia and Latin America (Geering et al., 1995; Refai, 2002). In Pakistan, there is little information on animal and human brucellosis. The epidemiosurveillance and bacteriological isolations of *Brucella* are very scarce. In the last few decades, brucellosis in ruminants has become a focused point for researchers resulting in a huge research gap for other vulnerable species. It is one of the most ignored diseases with respect to non-ruminants in Pakistan. Despite the detection of brucellosis in all domestic and wild animals, Pakistani people lack awareness regarding the zoonotic potential of this disease with their existing habit of raw milk consumption and close contact with infected animals. This review aims to describe the prevalence and epidemiology of brucellosis and encourage interested researchers to understand the brucellosis situation in Pakistan in a better way. For this purpose, available epidemiological data from 2000 to 2020 on non-ruminants and human brucellosis in Pakistan were analyzed using various search engines such as google scholar, Pubmed, Scopus and Web of Science. The geographical distribution of Brucellosis in non-ruminants and humans in Pakistan is illustrated in figure 1.

CAMEL BRUCELLOSIS

Investigations confirmed the presence of brucellosis in camels. Studies reported that seroprevalence of brucellosis may range from 0.51 % (Ullah 2015) to 21.0% (Baloch et al., 2016) in Pakistan. Fatima et al (2016) examined 200 camel sera using random and multi-cluster sampling from the lower Punjab of Pakistan. They found 5%, 2% and 1.5% sera positive using RBPT, cELISA and real-time PCR respectively. Shehzad et al., (2017) investigated 761 camel serum samples for brucellosis using RBPT and found 3.1% positives. The prevalence of brucellosis in camels belonging to various regions of Pakistan is summarized in table 2. A higher prevalence of brucellosis was recorded in the nomadic production system than in the organized production system. The seroprevalence of brucellosis was higher among adult camels than young ones and also higher in females compared to males (Fatima et al., 2016; Shahzad et al., 2017). With the increase in age, an increase in the level of hormones and erythritol may enhance the growth of

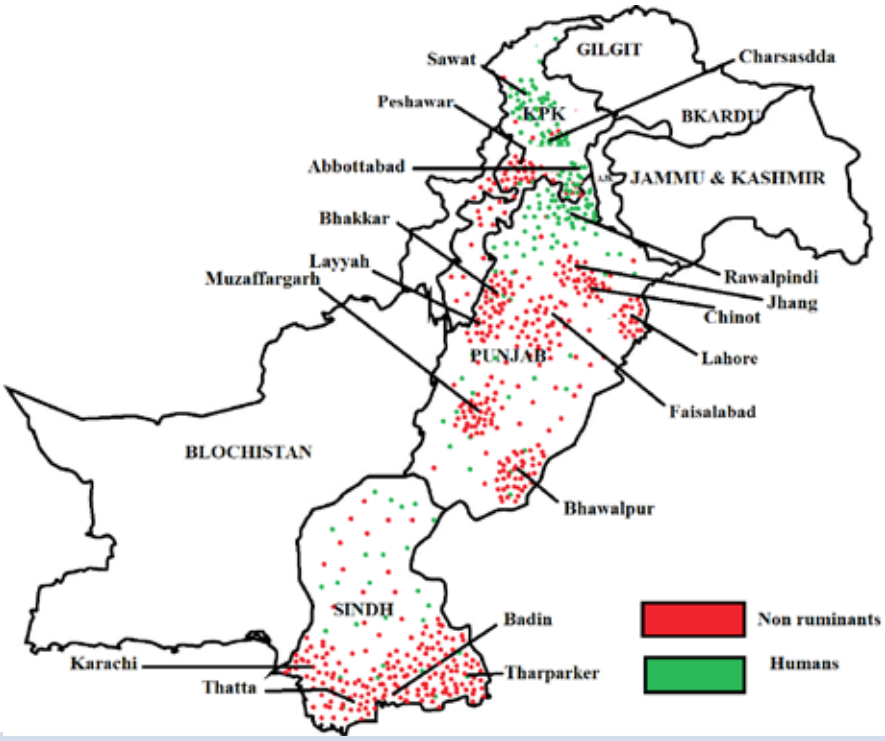


Fig 1: Geographical distribution of non-ruminant and human brucellosis in Pakistan

this pathogen (Poester et al., 2013). The high seropositivity of brucellosis was noticed in the animals with poor health status followed by moderate and good health status (Shahzad et al., 2017). The animals having more parity numbers were found more infected compared to the animals with fewer parity numbers (Shahzad et al., 2017). Fatima et al. (Fatima et al., 2016) suggested that brucellosis cases decrease in summer and spring and increase in winter because the pathogen does not survive in hot weather and cannot withstand direct exposure to sunlight. The study also described that sharing of common pastures and water points with infected animals had enhanced the transmission of brucellosis to camels.

EQUINES BRUCELLOSIS

Very few seroprevalence-based studies of equine brucellosis conducted in Pakistan. The prevalence range of equine brucellosis in Pakistan was reported as 16.23% (Gul et al., 2013) to 62.6% (Safirullah et al., 2014). Wadood et al., (2009) investigated 300 serum samples from equines and used RBPT and SAT. The overall prevalence was 20.7% by RBPT and 17.7% by SAT. All studies about the prevalence of equine brucellosis are presented in table 2. Females were more prone to this disease than males (Gul et al., 2013; Safirullah et al., 2014; Wadood et al., 2009). Wadood et al., (2009) observed that 9.6% of stallions and 17.7% mares were found infected with brucellosis. The higher prevalence in mares might be due to their close association with reproductive discharges passed after abortion or parturition by infected mares which can infect the healthy ones. Sexually matured animals are more susceptible to *Brucella*infection than sexually immature animals of either sex (Radostitis et al., 2007). Higher seroprevalence was found in those groups with the age of greater than 5 years than those groups with the age of less than or equal to 4 years (Gul et al., 2013; Safirullah et al., 2014; Wadood et al., 2009). Brucellosis prevalence was highest in the 6-10 years age group (20.26%) followed by 13.75% and 10.66% in 11-15 and 1-5 years age groups (Gul et al., 2013). The low prevalence can be explained on the basis that young animals may harbor the organism without expressing any detectable antibodies until their first parturition or abortion. Generally, the disease was more prevalent in animals of poor health condition while less in healthy animals (Safirullah et al., 2014; Wadood et al., 2009). Wadood et al., (2009) observed that 9.7%, 13.0% and 20.0% of seropositivity rate was found in good, fair and poor conditioned animals respectively.Wadood et al., (2009) also documented that desi breed was highly infected with brucellosis followed by Thoroughbred, Crossbred and Arabian horses in descending order. This study also revealed that chances of brucellosis increase with the increase of parity number in mares.

Table 2: Prevalence of brucellosis based on various diagnostic tests in non-ruminants and humans of Pakistan (2000-2020)

Year of studying	Diagnostic method	Camel	Equine	Dogs	Human	Avian	Reptiles	Amphibian	References
2001-2002	SAT	775 (1.8)							(Siddiqui, 2016)
2008	RBPT ELISA				300 (14) 300 (11)				(Ali *et al.,* 2013)
2008	ELISA				360 (21.7)				(Mukhtar and Kokab, 2008)
2009	RBPT SAT		300 (20.7) 300 (17.7)						(Wadood *et al.,* 2009)
2012	SPAT, PCR		500 (62.6)						(Safirullah *et al.,* 2014)
2012-2013	SPAT STAT PCR				300 (3.66) 300 (2) 300 (2.66)				(Ahmad *et al.,* 2017)
2013	RBPT SAT cELISA	100 (21) 100 (21) 100 (13)							(Baloch *et al.,* 2016)
2013	RBPT, SAT				262 (6.9)				(Hussain *et al.,* 2018)
2013	RBPT				429 (5.8)				(Ali *et al.,* 2016)
2013	RBPT SAT		308 (20.13) 308 (16.23)						(Gul *et al.,* 2013)
2014	SPAT PCR				200 (10) 200 (7.5)				(Perveen and Raqeebullah, 2015)
2014	SAT PCR				95 (38.94) 95 (14.7)				(Asif *et al.,* 2014)
2014-2015	RBPT qPCR				446 (10.1) 446 (5.8)				Saddique et al., 2019
2015	RBPT PCR	387 (0.51) 387 (0)							(Ullah, 2015)
2015-2016	SAT ELISA qPCR			87 (9.2) 87 (10.3) 87(1.15)					Jamil et al., 2019
2015-2016	SAT			94 (63.8)					
2016	RBPT cELISA qPCR	200 (5) 200 (2) 200 (1.5)							(Fatima *et al.,* 2016)
2016	RBPT, ELISA				250 (16)				(Sultan Ali *et al.,* 2018)
2016	RBPT					79 (2.5)	34 (24.9)	4 (25)	(Shahzad Ali *et al.,* 2018)
2016	SPAT RBPT PCR				73 (24.6) 73 (6.84) 73 (12.3)				Khan et al., 2018
2016	SPAT RBPT PCR				50 (30) 50 (4) 50 (18)				Khan et al., 2018
2017	SPAT PCR				200 (6) 200 (2)				(Khan *et al.,* 2017)
2017	RBPT	761 (3.41)							(Shahzad et al., 2017)
2017	SAT				70 (70)				(Malik *et al.,* 2018)
2018	SPAT				100 (23)				Maria Saif et al., 2018
2018	RBPT cELISA PCR				183 (8) 183 (13) 183 (33)				(Waheed *et al.,* 2018)

Figures in parenthesis indicate percentage and outside show total no. of samples examined

CANINE BRUCELLOSIS

The first-ever report on *B. canis* and *B abortus* in dogs of Pakistan reported by Jamil et al., (2019) showed the 9.2% and 10.3% serological prevalence of brucellosis in dogs of Faislabad district of Pakistan by SAT and ELISA respectively. Only one Elisa positive sample being founded positive for *B. abortus* through real-time PCR. They also reported 63.8% seroprevalence in dogs of Bahawalpur district of Pakistan with none of the sample was positive by Elisa and real-time PCR. One-year-old stray dogs were found positive against *B. canis* with poor body conditions. Moreover, *B. abortus* was detected from wounds present on the animal body. These findings highlight a risk of disease transmission from stray, wild and domestic dogs to livestock and humans and vice versa.

AMPHIBIANS, REPTILES AND BIRDS BRUCELLOSIS

To date, the epidemiology of *Brucella* infections in cold-blooded hosts is largely unknown. Shahzad et al., (2018) examined 117 blood samples from birds, amphibians and reptiles collected from the Sindh (Karachi) and Punjab (Pattoki) provinces of Pakistan. They found 11.11% samples seropositive for *Brucella* antibodies. More specifically, 25% avian, 29.4% reptiles and 25% amphibian samples were found seropositive using RBPT. In avian species, 6.25% peafowl and 9.1% Indian blue rock pigeons were diagnosed positive against brucellosis. In the case of amphibians and reptiles, 25% of Indian bullfrog and 32.3% yellow-spotted mud turtles were seropositive for *Brucella* antibodies respectively. These animals had no clinical signs of disease but could be a non-target species of brucellosis and can serve as a potential source of disease spread in marine, ground and flying birds. They can also pose a great risk to zoo laborers, veterinarians and shopkeepers.

HUMAN BRUCELLOSIS

The prevalence of brucellosis in humans may range from 2.0% (Ahmad et al., 2017) to 70% (Malik et al., 2018) in Pakistan. Waheed et al., (2018) collected 183 blood samples of occupationally exposed humans and tested using RBPT, cELISA and PCR and results revealed 8%, 13% and 33% samples positive respectively. Asif et al., (2014) examined 95 blood samples collected from veterinary professionals, livestock farmers and butchers. They found 38.94% and 14.7% of sample positives using SAT and PCR respectively. All prevalence-based studies are illustrated in table 2. Generally, it is found to be more common in males as compared to females. Sultan Ali et al., (2018) observed that the prevalence of brucellosis was higher in males (24%) than females (8%). In contrast, few studies reported that the disease is more common in females as compared to males (Ahmad et al., 2017; Khan et al., 2017; Malik et al., 2018). It was suggested that age constituted an important epidemiological risk factor for human brucellosis.Mukhtar and Kokab, (2008)reported that the age group of 51-60 years had the maximum seropositivity. While, Malik et al., (2018) documented that the majority of *Brucella*-positive individuals belonged to the age group 21-40 years. In another study, the highest prevalence of brucellosis was found in the age group ranging from 40-60 (Perveen and Raqeebullah, 2015). Young people showed higher prevalence than older because they were more engaged in working with livestock and also exposed to other occupational risks. In a study, 5.8% of pregnant Pakistani women were found to be seropositive and indeed women from rural areas were more often seropositive than those from urban areas (Ali et al., 2016). This study further revealed that pregnant women consuming raw milk were more often seropositive (76.5%) compared to those never consuming raw milk (2.9%). Sultan Ali et al., (2018) reported that individuals living in rural areas were 2.3 times more likely to be *Brucella* seropositive as compared to urban areas.Malik et al., (2018) found brucellosis among patients presenting with nonspecific symptoms. Symptoms were malaise, headache, insomnia, and fever. Lack of education and proper awareness about health and diet is the major reason for infections in the area. When the presence of infection was measured with education level, 83% of total patients were found to be illiterate (Ahmad et al., 2017). A high prevalence of *Brucella* infection was reported in those people having direct contact with animals and/or their products. The slaughterhouse workers are generally more susceptible to contract brucellosis by virtue of their direct exposure to viscera, gravid uterus and fetal membranes of infected animals (Mukhtar and Kokab, 2008). This study further revealed that brucellosis was found to be more common among individuals who had been involved in calf deliveries and had handled placenta. It is a significant finding that raw milk is a constant source of disease spread to farmers, milking men and general users. Disease prevalence was more in people associated with milking activities possibly due to the use of raw milk (Waheed et al., 2018).

Policy, response and control strategies

Treatment of brucellosis is not effective in animals. Career animals should be quarantined to limit the further spread and infected ones need culling based on screening and confirmatory tests (Falagas and Bliziotis, 2006). Brucellosis can be treated using a multi-drugs approach but treatment failure and relapse rates are very high (Pal et al., 2017). Antibiotic treatment can be used for genetically superior animals but due to uncertain outcomes, it is not recommended (Radostitis et al., 2007). Human treatment is possible and effective if this disease is diagnosed at an early stage and the patient gets effective drugs for an adequate length of time. A combination of doxycycline, rifampin, sulphamethoxazole, and trimethoprim are being used for treatment in humans (Alp et al., 2006; Khuri-Bulos et al., 1993; Yilmaz et al., 2004).

Most of the countries, particularly developed states, follow test and cull policy for infected animals to limit the spread of this disease among animal and human populations. This policy is not practicable in Pakistan due to limited resources to compensate the farmers for the slaughtering of infected animals(Mukhtar, 2010). Measures need to be followed for regular screening of the herd using RBPT, MRT, and PAT. Farmers should use screening tests while purchasing new animals from the market, if any animal is found positive, then avoid buying such an animal. A national eradication program has yet to propose for brucellosis in the country. The main hurdles limiting the control of brucellosis are the security of the country, shortage of funds, laboratory facilities and trained manpower. A human vaccine against brucellosis is not developed yet, therefore, the control of human brucellosis can only be possible by keeping animalsbrucellosis-free(Ning et al., 2013). In order to reduce the brucellosis burden in humans,mass vaccination not only in ruminants but also in non-ruminants can increase the resistance to infection in animals. To date, the brucella vaccine for dogs is not commercialized yet and trials are being conducted at the research level. Preventive measures for Brucella infection in dogs include spaying or neutering, giving antibiotics for several months, and frequent blood tests to monitor treatment progress.Pasteurization of milk and dairy products is another preventive measurement for humans. The development of powerful tactics is necessary to raise awareness in people about brucellosis, its zoonotic potential, the economic impact on the livestock industry and preventive measurements using extension services, leaflets, posters and other mass media. Mass vaccination not only in ruminants but also in non-ruminants can increase the resistance to infection in animals. Seroprevalence and epidemiology-based studies at the country level can help policymakers to propose a brucellosis eradication program in the country. Brucellosis control and eradication program should be initiated as in Egypt and Palestine (Eltholth et al., 2017; Awwad et al., 2018). In Egypt, two strategies are used. One is to test the animals and cull the infected ones based on positive serological tests. Another strategy is vaccination of the animal population. In Palestine, the brucellosis control program includes mass vaccination of animals and strengthening of their institutions for controlling and monitoring the disease.

CONCLUSION

Brucellosis poses a significant impact on human and animal health as well as socio-economic impact, particularly in those countries where rural income relies largely on livestock production and dairy products.Sharing of pastures, water and feeding points with infected animals should be avoided. High stocking density, the introduction of untested livestock animals from the market, lack of quarantine policy, and mixing of different species at the same farm are associated with a high prevalence of brucellosis in non-ruminants of Pakistan. In humans, males are found more susceptible as compared to females due to their occupational risks. The rural population of Pakistan harbors more infection than urban due to consumption of raw milk. Screening animals for brucellosis in villages and slaughterhouses is necessary and further attempts should be made to control this disease. Non-ruminants spread disease to humans as people are engaged at animal farms, treating animals and providing assistance in births. People keep dogs as a pet in their homes and they can be a source of infection, highlighting the need to screen pets on a routine basis. Detection of brucellosis in non-target species (reptiles, amphibians and birds) indicates the diverse host range of *Brucella* in Pakistan and increases the risk of infection not only for livestock animals but also for workers engaged with farm and wild animals. Vaccination in dairy animals is successfully being used but there is a dire need of time to vaccinate non-ruminants which may serve as an infection source for humans and animals. Programs to educate the agricultural people about brucellosis and food hygiene are needed to reduce the disease incidence. Due to the high prices of animals, the test and slaughter

policy is not an effective approach for the eradication of brucellosis in Pakistan. Testing, isolation, and management of infected animals in a quarantine system is the only viable approach to limit the spread of brucellosis. However, the impact of such policy in Pakistan has yet to be demonstrated.

CONFLICT OF INTEREST STATEMENT

None declared.

REFERENCES

Acha N &Szyfres B (2003) Zoonoses and Communicable Diseases Common to Man and Animals, 3rd ed. Pan American Health Organization (PAHO), Washington, DC

Ahmad H, Ali I, Ahmad T, Tufail M, Ahmad K & Murtaza BN (2017) Prevalence of Brucellosis in Human Population of District Swat, Pakistan. Pakistan Journal of Zoology 49:391-393. https://doi.org/10.17582/journal.pjz/2017.49.1.sc11

Ahmad SI and Rahman HU (2019). The emerging trend of brucella abortus zoonotic incidence in both human and animal population of district swat khyber-pakhtunkhwa. European J Biomed 6: 123-130.

Alfattli HHHH (2016) In Iraq, First Documentation of Canine Brucellosis by Application of Three Techniques (Rapid test, Indirect ELISA and 16S rDNA Inter-spacer PCR). Kufa J Vet Med Sci 7: 102-110.

Ali S, Akhter S, Neubauer H, Scherag A, Kesselmeier M, Melzer F, Khan I, El-Adawy H, Azam A, Qadeer S & Ali Q (2016) Brucellosis in pregnant women from Pakistan: an observational study. BMC Infect Dis 16: 468. https://doi.org/10.1186/s12879-016-1799-1.

Ali S, Ali Q, Neubauer H, Melzer F, Elschner M, Khan I, Abatih EN, Ullah N, Irfan M & Akhter S (2013) Seroprevalence and Risk Factors Associated with Brucellosis as a Professional Hazard in Pakistan. Foodbor Path Dis 10:500-505. https://doi.org/10.1089/fpd.2012.1360

Ali S, Nawaz Z, Akhtar A, Aslam R, Zahoor MA & Ashraf M (2018) Epidemiological Investigation of Human Brucellosis in Pakistan. Jundishapur Journal of Microbiology 11:. https://doi.org/10.5812/jjm.61764

Ali S, Saleem S, Imran M, Rizwan M, Iqbal K, Qadir G, Ahmad H, Umar S, Khan AW & Khan I (2018) Detection of Brucella antibodies in selected wild animals and avian species in Pakistan. Indian Journal of Animal Research. https://doi.org/10.18805/ijar.B-799

Alp E, Koc RK, Durak AC, Yildiz O, Aygen B, Sumerkan B &Doganay M (2006) Doxycycline plus streptomycin versus ciprofloxacin plus rifampicin in spinal brucellosis [ISRCTN31053647]. BMC Infectious Diseases 6:72. https://doi.org/10.1186/1471-2334-6-72

Asif M, Waheed U, Farooq M, Ali T & Khan QM (2014) Frequency of Brucellosis in High Risk Human Groups in Pakistan Detected through Polymerase Chain Reaction and its Comparison with Conventional Slide Agglutination Test. Int J Agric Biol 16: 6.

Awwad, E., Sbeih, Y., Awwad, O., Farraj, M., Essawi, T., Adwan, K., Manasra, A., Bărăităreanu, S., Gurău, M.R. and Daneş, D., 2018. Overview On The Epidemiological Situation And The Brucellosis' Control, Between 1974-2014, In West Bank, Palestine. *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Veterinary Medicine*, *75*(1), pp.104-110.

B. Lopes L, Nicolino R, P.A. & Haddad J (2010) Brucellosis - Risk Factors and Prevalence: A Review. Open Vet Sci J 4: 72-84. https://doi.org/10.2174/1874318801004010072.

Baloch AS, Rasheed A, Rind R, Sahito JK, Buriro R, Ayoob MF &Dewani P (2016) Seroprevalence of Brucellosis in Camels in Sindh, Pakistan. Pak J Zoo 49: 367-369. https://doi.org/10.17582/journal.pjz/2017.49.1.sc5

Dil S, Zahur AB, Qureshi S, Ullah A & Khan MA (2017) Brucellosis: A Threat to Human Population of District Rawalpindi. Annals of PIMS-Shaheed Zulfiqar Ali Bhutto Medical University, 13, 352-356.

Earhart K, Vafakolov S, Yarmohamedova N, Michael A, Tjaden J &Soliman A (2009) Risk factors for brucellosis in Samarqand Oblast, Uzbekistan. Int J Infect Dis 13:749-753. https://doi.org/10.1016/j.ijid.2009.02.014

Eltholth, M.M., Hegazy, Y.M., El-Tras, W.F., Bruce, M. and Rushton, J., 2017. Temporal analysis and costs of ruminant brucellosis control programme in Egypt between 1999 and 2011. *Transboundary and emerging diseases*, *64*(4), pp.1191-1199.

Falagas ME &sBliziotis IA (2006) Quinolones for Treatment of Human Brucellosis: Critical Review of the Evidence from Microbiological and Clinical Studies. Antimicrob Agents Chemother 50: 22-33. https://doi.org/10.1128/AAC.50.1.22-33.2006

Fatima S, Khan I, Nasir A, Younus M, Saqib M, Melzer F, Neubauer H & El-Adawy H (2016) Serological, molecular detection and potential risk factors associated with camel brucellosis in Pakistan. Trop Ani Heal Prod 48:1711-1718. https://doi.org/10.1007/s11250-016-1148-9

Fernando PP, Klaus N, Luis ES & Wei LY (2010) Diagnosis of brucellosis. Open Vet Sci J 4: 46-60.

Geering W, Forman A, Nunn M (1995) Exotic diseases of animals: a field guide for Australian veterinarians. Australian Government Publishing Service.

Godfroid J and KaÈsbohrer A (2002) Brucellosis in the European Union and Norway at the turn of the twenty first century. Vet Microbiol 11.

Godfroid J, Nielsen K &Saegerman C (2010) Diagnosis of Brucellosis in Livestock and Wildlife. Croatian Med J 51: 296-305. https://doi.org/10.3325/cmj.2010.51.296

Gorvel JP & Moreno E (2002) Brucella intracellular life: from invasion to intracellular replication. Vet Microbiol 90: 281-297. https://doi.org/10.1016/S0378-1135(02)00214-6

Gul ST, Khan A, Ahmad M & Hussain I (2013) Seroprevalence of brucellosis and associated hematobiochemical changes in pakistani horses. Pakistan J. Agri. Sci. 4: 50.

Hollett RB (2006) Canine brucellosis: Outbreaks and compliance. Theriogenology 66: 575-587. https://doi.org/10.1016/j.theriogenology.2006.04.011

Hussain I, Arshad MI, Mahmood MS & Akhtar M (2018) Seroprevalence of Brucellosis in Human, Cattle, and Buffalo Populations in Pakistan. Turkish J Vet Ani Sci 32: 315-318.

Jamil T, Melzer F, Khan I, Iqbal M, Saqib M, Hammad Hussain M, Schwarz S &Neubauer H (2019) Serological and Molecular Investigation of Brucella Species in Dogs in Pakistan. Pathogens 8: 294

Karthik K, Prabakar G, Indian Veterinary Research Institute, Izatnagar, Bareilly, U.P., India, et al (2016) Equine brucellosis: Review on epidemiology, pathogenesis, clinical signs, prevention and control. J Exp Biol Agri Sci 4:151-160. https://doi.org/10.18006/2016.4(Spl-4-EHIDZ).S151.S160

Karthik K, Rathore R, Thomas P, Elamurugan A, Arun TR &Dhama K (2014) Serological and Molecular Detection of Brucella abortus from Cattle by RBPT, STAT and PCR and Sample Suitability of Whole Blood for PCR. Asian J Ani Vet Adv 9: 262-269. https://doi.org/10.3923/ajava.2014.262.269

Khan A, Shafee M, Khan N, Rahman A, Rafiullah R, Ali I, Khan I &ur Rahman S (2018) Incidence of brucellosis in aborted animals and occupationally exposed veterinary professionals of Bannu, Khyber Pakhtunkhwa, Pakistan. Thai J Vet Med 48: 47-54.

Khan MZ, Usman T, Sadique U, Qureshi MS, Farooque M, Hassan MS & Khan A (2017) Molecular Characterization of Brucella abortus and Brucella melitensis in Cattle and Humans at the North West of Pakistan. Pak Vet J 37: 360-363.

Khan AU, Melzer F, Hendam A, Sayour AE, Khan I, Elschner MC, Younus M, Ehtisham-ul-Haque S, Waheed U, Farooq M & Ali S(2020) Seroprevalence and Molecular Identification of Brucella spp. in Bovines in Pakistan—Investigating Association With Risk Factors Using Machine Learning. Frontiers in veterinary science, 7.

Khuri-Bulos NA, Daoud AH &Azab SM (1993) Treatment of childhood brucellosis: results of a prospective trial on 113 children. Pediatr Infect Dis J 12: 377-381

Liu Q, Cao L & Zhu X-Q (2014) Major emerging and re-emerging zoonoses in China: a matter of global health and socioeconomic development for 1.3 billion. Int J Infect Dis 25: 65-72. https://doi.org/10.1016/j.ijid.2014.04.003

Malik S, Sarwar I, Rauf A & Haroon MZ (2018) Seroprevalence of brucellosis among patients presenting with non-specific symptoms at Ayub teaching hospital Abbottabad. J Ayub Med. Coll. Abbottabad, 30: 565-569.

Megid J, Antonio Mathias L, & Robles C (2010) Clinical Manifestations of Brucellosis in Domestic Animals and Humans. Open Vet Sci J 4: 119-126. https://doi.org/10.2174/1874318801004010119

Mühldorfer, K., Wibbelt, G., Szentiks, C.A., Fischer, D., Scholz, H.C., Zschöck, M. and Eisenberg, T., 2017. The role of 'atypical'Brucella in amphibians: are we facing novel emerging pathogens?. *Journal of applied microbiology*, *122*(1), pp.40-53.

Mukhtar F (2010) Brucellosis in a high risk occupational group: seroprevalence and analysis of risk factors. JPMA-J. Pakistan Med Assoc 60: 1031.

Mukhtar F, Kokab F (2008) Brucella serology in abattoir workers. J Ayub Med Coll Abbottabad 20: 57-61.

Neta AV, Mol JP, Xavier MN, Paixão TA, Lage AP & Santos RL (2010) Pathogenesis of bovine brucellosis. Vet J 184:146-155. https://doi.org/10.1016/j.tvjl.2009.04.010

Nicoletti P (2007) Brucellosis. In: Equine Infectious Diseases, Sellon DC, long MT. Saunders Elsevier, Philadelphia, pp 348-350

Ning P, Guo M, Guo K, Xu L, Ren M, Cheng Y & Zhang Y (2013) Identification and Effect Decomposition of Risk Factors for Brucella Contamination of Raw Whole Milk in China. PLoS ONE 8:e68230. https://doi.org/10.1371/journal.pone.0068230

Pal M, Gizaw F, Fekadu G, Alemayehu G & Kandi V (2017) Public Health and Economic Importance of Bovine Brucellosis: An Overview. American J Epi Infect Dis 5: 27-34. https://doi.org/10.12691/ajeid-5-2-2

Perveen, F and Raqeebullah, M.S (2015) Sero-prevalence of brucellosis in humans population of Charsasdda, Khyber Pakhtunkhwa, Pakistan. Int. J. Med. Invest. 4: 232-240.

Poester FP, Samartino LE & Santos RL (2013) Pathogenesis and pathobiology of brucellosis in livestock: -EN- -FR- -ES-. Revue Scientifiqueet Technique de l'OIE 32: 105-115. https://doi.org/10.20506/rst.32.1.2193.

Radostitis O, Gay C, Hinchcliff K & Constable P (2007) Veterinary medicine. A text book of the diseases of cattle, horses, sheep, pigs and goats, 10th ed. Saunders Elsevier, Edinburgh, London, New york. Oxford, Philadelphia, St. Louis, Sydney, Toronto

Refai M (2002) Incidence and control of brucellosis in the Near East region. Vet Microbiol 90: 81-110. https://doi.org/10.1016/S0378-1135(02)00248-1

Roop RM, Bellaire BH, Valderas MW &Cardelli JA (2004) Adaptation of the brucellae to their intracellular niche: Intracellular niche of the brucellae. Mol Microbiol 52: 621-630. https://doi.org/10.1111/j.1365-2958.2004.04017.x

Saddique A, Ali S, Akhter S, Khan I, Neubauer H, Melzer F, Khan AU, Azam A & El-Adawy H (2019) Acute febrile illness caused by Brucella abortus infection in humans in Pakistan. Int J Env Res Pub Healt 16: 4071.

Safirullah, Anwar K, Shahid M, Raza S, Khan N & Amin Y (2014) Epidemiological Study of Brucellosis in Equines of District Peshawar Khyber Pakhtunkhwa Pakistan. Int. J. Curr. Microbiol. App. Sci. 3, 795-800.

Shahzad A, Khan A, Khan MZ &Saqib M (2017) Seroprevalence and molecular investigation of brucellosis in camels of selected districts of Punjab, Pakistan. Thai J Vet Med 47: 207-215

Shin S & Carmichael LE (1999) Canine Brucellosis caused by B. canis. Recent Advances in Canine Infectious Diseases

Siddiqui A (2016) Incidence of camel brucellosis in Pakistan

Sprague LD, Al-Dahouk S &Neubauer H (2012) A review on camel brucellosis: a zoonosis sustained by ignorance and indifference. Path Glob Heal 106: 144-149. https://doi.org/10.1179/2047773212Y.0000000020

Ullah S (2015) Prevalence of Brucellosis among Camels in District Muzaffargarh, Pakistan. J Infect Mol Bio 3: 52-56. https://doi.org/10.14737/journal.jimb/2015/3.2.52.56

Wadood F, Ahmad M, Khan A, Gul ST & Rehman N (2009) Seroprevalence of brucellosis in horses in and around Faisalabad. Pak. Vet. J. 29, 196-198.

Waheed U, Butt ZN, Ashraf WO & Khan QM (2018) Seroprevalence and Molecular Epidemiosurveillance of Brucellosis in Pakistan. Online J Public Health Inform 10. https://doi.org/10.5210/ojphi.v10i1.8647

Wanke MM (2004) Canine brucellosis. Ani repro sci 82: 195

Wareth, G., Kheimar, A., Neubauer, H. and Melzer, F., 2020. Susceptibility of Avian Species to Brucella Infection: A Hypothesis-Driven Study. *Pathogens*, *9*(2), p.77.

Yilmaz E, Parlak M, Akalin H, Heper Y, Ozakin C, Mistik R, Oral B, Helvaci S &Töre O (2004) Brucellar Spondylitis: Review of 25 Cases. JCR: Journal of Clinical Rheumatology 10:300-307. https://doi.org/10.1097/01.rhu.0000147048.44396.90