Brucellosis in Cattle: Evolution, Transmission and Zoonotic potential

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Abstract

Brucellosis, mostly caused by *Brucella abortus* in cattle, is a serious zoonotic disease that affects human health, animal health, and the sustainability of economy. The capacity of *Brucella spp.* to adapt to intracellular conditions, elude host immune responses, and cause persistent infections is thought to be the reason for their evolutionary success. Due to these modifications, the disease has been able to continue to exist in cow herds, sustaining endemic cycles in a variety of geographic locations. Cattle can contract the disease directly via infected fluids, aborted tissues, or milk, or indirectly through tainted feed or water. Herds are further contaminated by vertical transmission from diseased dams to their progeny. Abortions, infertility, and reduced productivity are among the clinical indications that cause cattle companies to suffer large financial losses. Particularly for those who handle cattle or consume unpasteurized dairy products, the zoonotic potential of brucellosis is a serious issue. In humans, brucellosis presents as a feverish disease with long-term consequences, requiring prompt diagnosis and intensive care. In order to prevent the spread of brucellosis and lessen its zoonotic dangers, this chapter emphasizes the significance of integrated strategies that include immunization, efficient diagnostics, and public awareness.

Keywords: Brucellosis, *Brucella abortus*, Zoonosis, Cattle, Human, Integrated strategies.

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Introduction

Cattle brucellosis, often known as Bang's disease, is a major economic issue (Mcmahan et al., 1944). *Brucella* is a non-motile, Gram-negative coccobacillus. It is a member of the alpha-Proteobacteria, which also includes *Agrobacterium, Rickettsia, Rhodobacterium*, and *Rhizobium* in addition to *Brucella*. But recently, diseased frogs were used to isolate atypical motile *Brucella* isolates. Most references classified *Brucella* as a facultative intracellular pathogen, but because of their evolutionary relationship to other alpha-Proteobacteria, they were reclassified as facultative extracellular intracellular pathogens. Brucellae are stealth microbes that prefer to induce chronic infections over acute ones (El-Sayed & Awad, 2018). It is one of the most expensive diseases, causing health problems in both rural and urban areas as well as large losses for the offspring (Maadi et al., 2011).

It was difficult to place the newly discovered atypical *Brucella spp.* (particularly *B. microti* and *B. inopinata*) because they clearly differed from the classical ones on phenotypic and genetic levels. Both species grow quickly and have very active metabolisms. However, the old debate returned after the new *Brucella spp.* were discovered. At least twelve species of *Brucella* were known at the time. Due to its significant zoonotic and economic significance, it is crucial to identify field isolates of *Brucella* by both species and genotype. This makes it possible to identify concealed *Brucella* foci and track down the population's infection origins (El-Sayed & Awad, 2018).

Similar to Gram-negative bacteria, brucellae have an exterior cell membrane. A smooth lipopolysaccharides (LPS) surface antigens A and M are present; *B. suis* and *B. abortus* have the A antigen as their primary antigen, whereas *B. melitensis* has the M antigen. Many immunological tests target these LPS, which are also important virulence factors. In addition to cytoplasmic and periplasmic proteins, some outer and inner membranes are important for a variety of cellular processes. The development of diagnostic tests can also benefit from the usage of outer membrane proteins (Khurana et al., 2021).

Since brucellosis in livestock (pigs, small ruminants, and cows) has been eradicated in several affluent nations, it has taken on an exotic or foreign appearance. Reaching and maintaining a "brucellosis-free" status in cattle is crucial from an economic perspective so that live animals can be freely traded without the need for expensive brucellosis testing prior to transportation. According to this viewpoint, under some circumstances, the existence of a reservoir of *Brucella spp.* in wildlife is regarded as a threat; in fact, the spread of *Brucella spp.* to livestock, or "spillback" infection, may endanger the livestock's status as brucellosis-free, with catastrophic economic repercussions (Godfroid, 2018).

Evolution

Brucellosis, also known as Bang's disease, undulant fever, Mediterranean fever, or Malta fever, is a highly contagious re-emerging zoonotic illness of public health and economic importance that is caused by several species of *Brucella*. During the Crimean War in Malta in the 1850s, British medical officials became aware of brucellosis for the first time under the name Malta fever. In 1861, Jeffrey Allen Marston (1831–1911) wrote about his personal experience with the illness. David Bruce was the first to discover the link between an organism and sickness in 1887. Bruce's identified agent was categorized as a coccus. The term "Bang's disease" was coined in 1897 when Danish veterinarian Bernhard Bang identified a Bacillus as the cause of increased spontaneous abortion in cows (Berhanu & Pal, 2020).

The genus *Brucella* contains facultative intracellular extracellular pathogens that produce the unpleasant illness brucellosis. In domesticated animals, brucellosis primarily manifests as abortion and epididymitis. In natural settings, *Brucella* can spread either horizontally or vertically. The bacterium preferentially develops inside the phagocytic cells of the reticuloendothelial system and placental trophoblasts of the pregnant animal. Although *Brucella* has been demonstrated to persist for some time in open environments, it rarely splits and eventually dies.

Nevertheless, these two recent occurrences are not epidemiologically significant and do not contribute significantly to the spread of brucellosis (Moreno, 2014). South Eastern Europe, the Middle East, the Mediterranean, Asia, Sub-Saharan Africa, and a number of Latin American nations are endemic for brucellosis (Nicoletti, 2010).

A dangerous infectious disease that affects many animal species, including humans, is brucellosis. Farm animals can become naturally infected by licking the genitalia of sick animals or by consuming food or water tainted by fetal membranes, feces, or uterine discharges. Although it was previously believed that infected people were the virus's dead end, human-to-human transmission has lately been documented. Direct and indirect contact with diseased animals or foodstuffs of animal origin is the main source of infection to humans (El-Sayed & Awad, 2018). For endemic zoonotic illnesses, an improvised worldwide surveillance and control system is not (and should not be) used. In fact, endemic and epidemic diseases are fundamentally distinct and do call for different strategies (Godfroid, 2017).

For instance, once endemic diseases have reached the stage of endemic stability, as is frequently the case under conventional husbandry systems in the developing countries, it is pointless to put in place an early detection/warning system, which is the first step in any program to manage epidemic diseases. With over 500,000 new cases each year, human brucellosis continues to be the most prevalent zoonotic disease in the world. Numerous types of *Brucella* are responsible for the disease, which primarily affects sheep, goats, pigs, and cattle. Humans typically contract the infection by inhaling airborne agents, eating or drinking contaminated animal products, or coming into close contact with diseased animals (Godfroid, 2017).

Transmission

One of the oldest and most common zoonotic illnesses is brucellosis (Adugna et al., 2013). There are two ways that *Brucella* can spread: horizontally and vertically. Animals that are pregnant have increased concentrations of *Brucella* germs in their uterus. The primary sources of infection are the placental membranes, uterine secretions, and aborted fetuses. Infected animals may pass the virus on to their offspring through their milk. The organism can persist in the environment for months at a time, particularly in a moist and chilly environment. The animals get infected by consuming tainted food and water, or by coming into touch with fetal membranes, uterine secretions, or aborted babies. Another way of transmission might be inhalation (Khurana et al., 2021).

A direct contact and environmental contamination are the two ways that *Brucella* is spread. Aerosols, milk, sexual fluids, and abortive materials are among the biological secretions of infected animals that contain the germs. Therefore, there is a considerable possibility of an infectious disease spreading between nations through cross-border cattle trading and seasonal transhumance. Animals can become infected through transhumance, mixing at livestock markets, communal herding and grazing, and the addition of diseased animals to a herd (Oyetola et al., 2021). There were noticeable seasonal differences in the prevalence of brucella infection, with a higher prevalence during the dry season. The fact that animals moving by transhumance during dry spells often congregate at watering stops and share a pasture area may help to explain the high incidence (Bayemi et al., 2015).

Pathogenesis

Following phagocytosis, brucella enters the bloodstream through lymph nodes and causes bacteremia, a condition marked by an acute febrile phase. The reticuloendothelial system, liver, spleen, and many other places, such as the joints, kidneys, heart, and genital tract, are home to bacteria that are derived from blood. In addition to being associated with nutrition intake and the export of toxins and antibiotics, the bacterial ABC transporter system may play a critical role in the expression of specific genes. The ability of *Brucella* to survive and proliferate within host cells after eluding the host's defense mechanisms is linked to its capacity to stop lysosomes from merging with phagosomes, which results in degranulation and the activation of the myelo-peroxidase-halide system, as well as to stop tumor necrosis factors and cell death in host cells (Khairullah et al., 2024).

The decrease in cow fertility brought on by abortions and the decrease in milk output are the main causes of the financial losses associated with brucellosis in animals. Abortion is the primary sign of brucellosis in animals, however after a prolonged illness, testicular enlargement and arthritis (hygroma) can also be seen. Since test diagnosis is required to confirm infection, clinical diagnosis is challenging and complicates border checks. Because the infection is frequently mistaken for other feverish illnesses in people, therapy is inefficient, expensive, and morbid, making it impossible to work (Oyetola et al., 2021).

The bull's reproductive tract is where *Brucella abortus* is found. High levels of erythritol are seen in genital tract cells, which promotes the proliferation of this zoonotic pathogen. The orchitis, epididymitis, seminal vesiculitis, ampullitis, lowered libido, and infertility can all result from infection. Additionally, the organism may be found in semen that has been collected (Givens, 2018). The rose Bengal plate agglutination test was used as a screening test and the complement fixation test was used as a confirmatory test to examine the seroprevalence of brucellosis in various Egyptian locations. The estimated seroprevalence of brucellosis in sheep flocks in the governorates of Kafr El-Sheikh and Giza was 41.3% and 11%, respectively (Hegazy et al., 2022). With a 94% nucleotide-level similarity throughout the genus, brucellae defend against DNA changes using a variety of defense mechanisms (Olsen & Tatum, 2010).

Zoonotic Potiential

Understanding the biology of *Brucella* infection, the ecology of *Brucella* infection in complex systems involving multiple hosts, and the factors influencing changes in the epidemiology of *Brucella* infection are essential for developing and implementing effective mitigation strategies. This is true for any zoonosis at the wildlife/livestock/human interface. It is crucial to recognize that these tactics will be applied from various angles, including or not OH, since they have distinct goals. Preventing discipline-specific "silos" that rarely interact with one another and are likely to (at best) only partially address the concerns of some interested groups requires that these various goals be clearly highlighted beforehand to allow stakeholders to take ownership (Godfroid, 2018).

Brucellosis, especially *B. melitensisis*, is expected to affect over 50,000 people every year, making it one of the most common re-emerging zoonotic diseases in the world. The increased global trade in livestock products, rapid destruction of forests, unplanned and unnatural growth, urbanization, intensive farming, migratory/nomadic animal husbandry, and increased international travel and tours have all added to the zoonotic significance of brucellosis. The economy and welfare of animals are severely impacted by brucellosis. The cumulative effect of decreased milk production, abortions, stillbirths and abortion-related losses of newborn calves, culling of animals with brucellosis, obstructing animal export and trade, human effort loss in terms of lost man-days, veterinary and medical costs, and administrative and governmental expenditures on research and control programs constitutes the collective economic losses (Khurana et al., 2021).

It is commonly known that the frequency of brucellosis in animals and Maltese fever in humans is related. Strong livestock management techniques that maintain the wellbeing of animal reservoirs are essential for the effective control of this zoonotic illness in human populations. Preventing animal brucellosis is a key method for protecting human health, according to the WHO's Mediterranean Zoonosis Control Program. A 'test-and-slaughter' strategy and extensive immunization programs are important strategies to reduce the risk of transmission. In Iran, brucellosis vaccination campaigns began in 1944. However, their execution was impacted by a number of social, political, and economic issues (Izadi et al., 2024). The sexes did not differ significantly in Brucella seropositivity (Otlu et al., 2008)

In livestock animals (cattle, sheep, goats, pigs, and camels), abortion is the most frequent clinical sign following a Brucella infection. Although *B. suis* or, more commonly, *B. melitensis* can infect cattle that share pasture or facilities with sick pigs, goats, or sheep, *B. abortus* is the most prevalent infection in cattle. Public health is seriously threatened by the spread of *B. suis* and *B. melitensis*, which are found in cow's milk (Seleem et al., 2010).

Humans can contract zoonotic diseases from animals through direct contact, as well as through food, water, and the environment. This poses a serious threat to public health. A classic example of a zoonotic disease that is common worldwide is brucellosis, which is brought on by several species of the genera *Brucella*. The World Health Organization (WHO) has identified brucellosis as one of the most neglected zoonotic diseases. It is still a serious epidemic, especially in low- and middle-income nations. Through the gastrointestinal tract, respiratory system, mucous membranes, or abraded skin, the *Brucella* pathogens infect and infiltrate the host (Zhou et al., 2020). There are currently no effective vaccines to prevent human brucellosis, despite the apparent potential of attenuated pure mutations (Corbel, 1997)

The human infections are more frequently linked to the use of and consumption of animal-based foods. The largest risk groups include veterinarians, animal farmers, and slaughterhouse workers, who typically contract infections through mucous or abraded skin. Spontaneous miscarriage, undulant fever, and occasionally mastitis are the symptoms of infection. Although animal brucellosis is typically subclinical, it nevertheless costs the cattle business a lot of money. The majority of infection cases in companion animals are often mild or asymptomatic. Therefore, because of their cryptic pathophysiology and clinical manifestations, brucellosis in agricultural and domestic animals is typically undervalued (Zhou et al., 2020).

Diagnosis

The absence of clear standards for diagnosing instances of brucellosis is a significant contributing factor to this disorder. Researchers hypothesized that following acute brucellosis, the immune response is primarily composed of IgM, the secondary immune response is in the form of IgG, which typically weakens after the condition improves, and that there is no permanent positivity to IgG antibody for a longer period of time. An examination of the disease's clinical and diverse serological pattern served as the foundation for this notion. Early and precise diagnosis is essential for the therapeutic management and control of infection (Khurana et al., 2021).

Along with other metabolic traits, a polyvalent Brucella-antiserum in a slide agglutination test reaction detects the presence of surface antigens, which are commonly employed to isolate Brucella. Additionally, specialized labs are made to distinguish between the three most dangerous species of *Brucella*. Gruber-Widal's agglutination method is a methodical way to identify antibodies and differentiate between bacteria. The direct Coombs test and the complement binding response can be used to get a serological diagnosis under unclear circumstances (Berhanu & Pal, 2020).

In spring and fall 2008, respectively, 82 and 256 milk samples were randomly chosen from 11 and 25 villages to detect *Brucella abortus* antibodies in Urmia cattle. Teats were cleaned with alcohol and allowed to dry before the first streak of milk was discharged into sterile tubes, which were then placed in ice and brought to the laboratory. The Milk Ring Test (MRT) was performed (Morgan et al., 1978). To put it simply, 0.03 µl of *Brucella abortus* antigen (from Iran Pasteur Institution) was added to 1000 µl of milk, thoroughly mixed, and incubated at 37°C for an hour before the results were analyzed for ring formation (Maadi & Haghi, 2011)

The most reliable test for identifying *Brucella spp.* is the isolation and culture of the bacterium, even though there are other diagnostic techniques available. It is advised to utilize selective media, such as Farrell's medium, because all strains of *Brucella* develop fairly slowly due to the frequently contaminated specimens used for isolation. These days, the polymerase chain reaction, or PCR, is one of the most popular techniques for identifying brucellosis in both humans and animals. This disease can be confirmed if bacteria are detected in the smear. Smears are created from the placenta, colostrum, fetal stomach fluid, or lochia of post-abortive cows and the abomasum of aborted fetuses using modified Ziehl-Neelsen staining (Khairullah et al., 2024).

The ELISA has grown in favor as a standard brucellosis diagnosis method. This is an excellent method for screening large populations for *Brucella* antibodies and distinguishing acute from chronic illness phases. The ELISA method makes it remarkably easy to identify all four types of antibodies (IgG1, IgG2, IgA, and IgM). The SAT is one of the frequently used serological tests to identify brucellosis. This method is easy to apply and doesn't require expensive equipment or specific understanding. SAT measures the levels of total IgM and IgG agglutination antibodies (Khairullah et al., 2024).

The bacterial culture techniques and other serological approaches are the primary means of detection. These methods also aid in monitoring programs, herd screening, and the development, management, and eradication of strategies in various parts of the world. The main disadvantage of PCR-based techniques is their inability to differentiate between the field strain and the vaccination strain, despite reports that they are successful in detecting brucellosis in livestock. Confirmatory diagnosis of brucellosis requires laboratory confirmation from serum samples (Khurana et al., 2021).

Serologic procedures like 2-mercaptoethanol agglutination, the Coombs test, Burnet's intradermal test, which can determine the level of hypersensitivity of an infected patient to *B. abortus*, and the detection of antibodies produced in response to infection by CFT are the main methods for diagnosing brucellosis. Isolation of bacterial pathogens is the gold standard and always a verified diagnosis. However, drawbacks include the lengthy process typically two weeks needed for conclusive identification (Khurana et al., 2021).

Treatment

The standard combination treatments for adult acute brucellosis include 200 mg of doxycycline taken orally daily in conjunction with 600–900 mg of rifampicin taken orally daily for 6 weeks, 100 mg of doxycycline taken orally twice daily for 6 weeks in conjunction with 1 g of streptomycin intramuscularly daily for 2-3 weeks, or 100 mg of doxycycline taken orally twice daily for 6 weeks in conjunction with parenteral administration of gentamicin (5 mg/kg body weight for 7 days). When 500 mg/12 hours of tetracycline was given orally for two weeks, mild instances showed positive results (Berhanu & Pal, 2020). Because it reduces the initial quantity of germs and may influence the establishment of a protective adaptive immunity, innate immunity is crucial during a *B. abortus* infection (Neta et al., 2010).

Impact on Public Health

The public health is severely harmed by human brucellosis in areas where it is endemic. Both humans and farm animals are susceptible to brucellosis, a zoonotic disease that is economically significant worldwide. In most parts of the world, it is a major public health issue for both humans and animals. Due to effective vaccination-based fully managed packages, the prevalence of brucellosis has significantly declined in the developed world; however, the disease is still an uncontrolled problem in high endemic regions of the Mediterranean, Middle East, Africa, Latin America, and parts of Asia. Since animals are the main source of infection for people, controlling livestock mainly ruminants is essential to lessening the disease's impact on public health (Holt et al., 2021). It is thought that people can contract illnesses from animals (Samaha et al., 2009). Human zoonotic transmission may be facilitated by certain rural residents' use of unpasteurized milk and farmers' overall disregard for safety measures (Kubuafor et al., 2000).

Although the frequency of brucellosis has been considerably decreased in the developed world by effective vaccination-based completely managed packages, the disease remains uncontrolled in high endemic regions of the Mediterranean, Middle East, Africa, Latin America, and portions of Asia. A major economic concern, brucellosis is an infectious zoonosis that affects both humans and farm animals globally (Berhanu & Pal, 2020).

Control and Prevention Measures

When developing and accessing intervention strategies for disease control and prevention, modelling is a useful tool (Tumwiine & Robert, 2017). Although the national effort for brucellosis control started almost four years earlier, in 1967, the immunization program in Isfahan did not start until 1971. Iran began using RB51 as a brucellosis vaccine in 1967. It is produced by Iran's Pasteur Institute. Since 2004, it has been required for heifers between the ages of 4 and 6 months to get a full dose of the brucellosis vaccine. Additionally, it is recommended that cows that have received vaccinations receive a lower dosage for revaccination every two years. Every cow ranch has its own vaccination schedule that is tailored to the particular requirements of the farms. The fact that brucellosis vaccination services are free in Iran should not be overlooked (Izadi et al., 2024).

Isolating afflicted patients is less important because brucellosis is not communicable, even though avoiding viral exposure is essential for managing and preventing infections. Currently, there is no commercial vaccine that can be used to vaccinate high-risk populations (Berhanu & Pal, 2020). The most significant factor influencing an eradication program's efficacy is the disease's prevalence (Yoon et al., 2014).

Between 1990 and 2010, Iran's immunization programs significantly reduced the prevalence of brucellosis, with the most remarkable reductions occurring in Isfahan Province. This demonstrated that the illness was contained (Izadi et al., 2024). Milk must be pasteurized before consumption in order to stop the infection from spreading to people. Consuming unpasteurized milk products from unsanitary dairy farms where brucellosis is endemic poses a serious risk to public health. The history of the disease, epidemiological patterns, and related data are essential for the clinical diagnosis of brucellosis. The World Health Organization (WHO) stated in its factsheet that although though millions of brucellosis cases are recorded each year, the actual incidence rate is still 10–25 times greater (Khurana et al., 2021).

To lessen the disease's negative effects on the economy and public health, new strategies for brucellosis control that take transboundary cattle immigration into account are crucial. Understanding the variables that can account for the role that cattle migration plays in the spread of brucellosis is crucial for this (Oyetola et al., 2021). We can better understand how infectious diseases spread with the aid of mathematical modeling. Numerous models have been put forth over time to investigate the dynamics of zoonosis (Figure 1). In particular, Nyerere et al. developed a mathematical model to investigate how various control parameters affect the dynamics of brucellosis transmission in both human and animal populations. They concluded that the only way to prevent human brucellosis is to prevent domestic animal diseases (Abagna et al., 2022). The public should be informed about the disease, farmers should receive vaccinations, and suitable national control measures should be implemented (Mai et al., 2012).

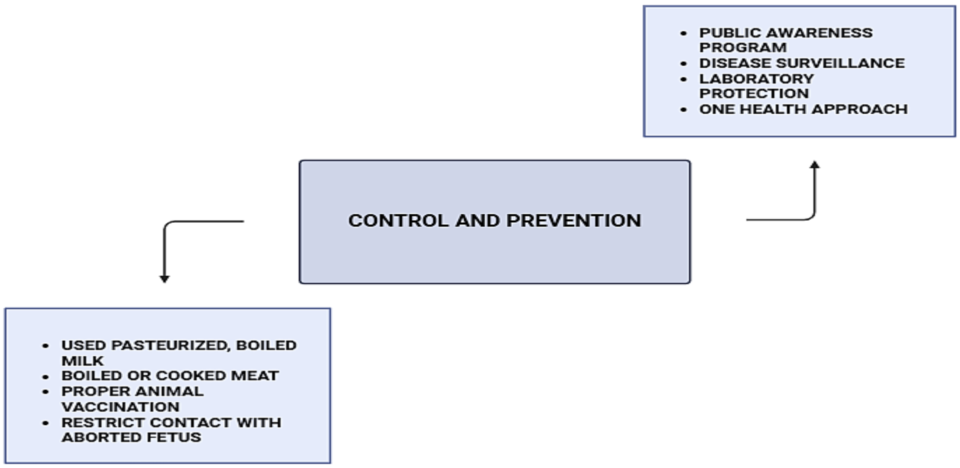

Fig. 1: Berhanu, G., & Pal, M. (2020). Brucellosis: A highly infectious zoonosis of public health and economic importance. *Journal of Emerging Environmental Technologies and Health Protection*, *3*, 5-9.

Conclusion

Brucellosis, a systemic communicable disease, has significant public health concerns, consisting of direct and indirect route of transmission among animals. Public health is also at risk, considering its zoonotic potential, humans rarely have one-to-one transmission, but seriously affects reproduction. Mostly people having a direct contact with animals are prone to brucellosis. Brucellosis seed economic challenges particularly in developing countries as it causes decline in livestock production and as existing animals suffering from brucellosis are culled. Further the cost of treatment for brucellosis is a financial burden not only for animals but also for humans. Modern techniques involve prevention and control rather than treatments which include selective antibiotics. Occupational groups in veterinary field require a deep knowledge of prevention, control, handling carcasses and infective tissues to protect themselves from any kind of disease. Proper arrangements should be made to reinforce biosecurity and biosafety measures, equipped with all PPEs (personal protective equipment's). The pyrexia (fever) of unknown origin in humans should not be neglected and should be checked upon on for brucellosis. Right diagnosis requires adequate laboratory examination. Due to continuous mutation, new *Brucella spp.* are being discovered. Between 1968 and 2007, new species of *Brucella* were not identified but after 2007, there a boom in discovery of new *Brucella* species with a significant zoonotic potential. *Brucella* concerns include potential reemergence, for which prior preventive measures should be taken. Vaccine's development has indispensable effects, in controlling brucella surge. Control programs designed to combat surge challenges are essential for wholesome living. For this disease to be controlled, eventually eradicated, and monitored, diagnosis and immunization are crucial. (Ducrotoy et al., 2018).

References

Abagna, S., Seidu, B., & Bornaa, C. S. (2022). A mathematical model of the transmission dynamics and control of bovine brucellosis in cattle. In *Abstract and applied analysis* (Vol. 2022, No. 1, p. 9658567). Hindawi.

Adugna, K. E., Agga, G. E., & Zewde, G. J. R. S. T. (2013). Seroepidemiological survey of bovine brucellosis in cattle under a traditional production system in western Ethiopia. *Revue Scientifique et Technique*, *32*(3), 765-73.

Berhanu, G., & Pal, M. (2020). Brucellosis: A highly infectious zoonosis of public health and economic importance. *Journal of Emerging Environmental Technologies and Health Protection, 3*, 5-9.

Bayemi, P. H., Mah, G. D., Ndamukong, K., Nsongka, V. M., Leinyuy, I., Unger, H., & Luogbou, N. D. (2015). Bovine brucellosis in cattle production Systems in the Western Highlands of Cameroon. *International Journal of Animal Biology*, *1*(2), 38-44.

Corbel, M. J. (1997). Brucellosis: an overview. *Emerging Infectious Diseases*, *3*(2), 213-221.

Ducrotoy, M. J., Muñoz, P. M., Conde-Álvarez, R., Blasco, J. M., & Moriyón, I. (2018). A systematic review of current immunological tests for the diagnosis of cattle brucellosis. *Preventive Veterinary Medicine*, *151*, 57-72.

El-Sayed, A., & Awad, W. (2018). Brucellosis: Evolution and expected comeback. *International Journal of Veterinary Science and Medicine, 6*, S31-S35.

Givens, M. (2018). Risks of disease transmission through semen in cattle. *Animal, 12*(s1), s165-s171.

Godfroid, J. (2017). Brucellosis in livestock and wildlife: zoonotic diseases without pandemic potential in need of innovative one health approaches. *Archives of Public Health, 75*(1), 34.

Godfroid, J. (2018). Brucella spp. at the wildlife-livestock interface: an evolutionary trajectory through a livestock-to-wildlife "host jump"?

Veterinary Sciences, 5(3), 81.

Hegazy, Y. M., Abdel-Hamid, N. H., Eldehiey, M., Oreiby, A. F., Algabbary, M. H., Hamdy, M. E., & García, N. (2022). Trans-species transmission of Brucellae among ruminants hampering brucellosis control efforts in Egypt. *Journal of Applied Microbiology, 132*(1), 90-100.

Holt, H. R., Bedi, J. S., Kaur, P., Mangtani, P., Sharma, N. S., Gill, J. P. S., & Guitian, J. (2021). Epidemiology of brucellosis in cattle and dairy farmers of rural Ludhiana, Punjab. *PLoS Neglected Tropical Diseases*, *15*(3), e0009102.

Izadi, S., Moghaddas, V., Feizi, A., Bahreinipour, A., & Barati, Z. (2024). Bovine brucellosis, associated risk factors and preventive measures in industrial cattle farms. *Heliyon, 10*(22). e40180.

Khairullah, A. R., Kurniawan, S. C., Puspitasari, Y., Aryaloka, S., Silaen, O. S. M., Yanestria, S. M., & Riwu, K. H. P. (2024). Brucellosis: Unveiling the complexities of a pervasive zoonotic disease and its global impacts. *Open Veterinary Journal, 14*(5), 1081-1097. doi:10.5455/OVJ.2024.v14.i5.1

Khurana, S. K., Sehrawat, A., Tiwari, R., Prasad, M., Gulati, B., Shabbir, M. Z., & Pathak, M. (2021). Bovine brucellosis–a comprehensive review. *Veterinary Quarterly, 41*(1), 61-88.

Kubuafor, D. K., Awumbila, B., & Akanmori, B. D. (2000). Seroprevalence of brucellosis in cattle and humans in the Akwapim-South district of Ghana: public health implications. *Acta Tropica*, *76*(1), 45-48.

Mai, H. M., Irons, P. C., Kabir, J., & Thompson, P. N. (2012). A large seroprevalence survey of brucellosis in cattle herds under diverse production systems in northern Nigeria. *BMC Veterinary Research*, *8*, 1-14.

Mcmahan, V. K., Roderick, L. M., & Kitselman, C. K. (1944). *Brucellosis of cattle*. Agricultural Experiment Station, Kansas State College of Agriculture and Applied Science.Pp 1-16.

Moreno, E. (2014). Retrospective and prospective perspectives on zoonotic brucellosis. *Frontiers in Microbiology, 5*, 213.

Morgan, W. B., Mackinnon, D. J., Gill, K. P. W., Gower, S. G. M., & Norris, P. I. W. (1978). Brucellosis diagnosis-standard laboratory techniques. 2nd edition, 53pp.

Maadi, H., Moharamnejad, M., & Haghi, M. (2011). Prevalence of Brucellosis in cattle in Urmia, Irán. *Pakistan Veterinary Journal, 31*(1), 81-82.

Neta, A. V. C., Mol, J. P., Xavier, M. N., Paixão, T. A., Lage, A. P., & Santos, R. L. (2010). Pathogenesis of bovine brucellosis. *The Veterinary Journal*, *184*(2), 146-155.

Nicoletti, P. (2010). Brucellosis: past, present and future. *Prilozi*, *31*(1), 21-32.

Otlu, S., Sahin, M., Atabay, H. I., & Unver, A. (2008). Serological investigations of brucellosis in cattle, farmers and veterinarians in the Kars district of Turkey. *Acta Veterinaria Brno*, *77*(1), 117-121.

Oyetola, W. D., Diallo, K., Kreppel, K., Kone, P. S., Schelling, E., Bonfoh, B., & Bada Alambedji, R. (2021). Factors influencing the transborder transmission of brucellosis in cattle between Côte d'Ivoire and Mali: Evidence from literature and current key stakeholders. *Frontiers in Veterinary Science, 8*, 630580.

Olsen, S., & Tatum, F. (2010). Bovine brucellosis. *Veterinary Clinics: Food Animal Practice*, *26*(1), 15-27.

Samaha, H., Mohamed, T. R., Khoudair, R. M., & Ashour, H. M. (2009). Serodiagnosis of brucellosis in cattle and humans in Egypt. *Immunobiology*, *214*(3), 223-226.

Seleem, M. N., Boyle, S. M., & Sriranganathan, N. (2010). Brucellosis: a re-emerging zoonosis. *Veterinary Microbiology*, *140*(3-4), 392-398.

Tumwiine, J., & Robert, G. (2017). A mathematical model for treatment of bovine brucellosis in cattle population. *Journal of Mathematical Modeling*, *5*(2), 137-152.

Yoon, H., Moon, O. K., Lee, S. H., Lee, W. C., Her, M., Jeong, W., & Kim, D. S. (2014). Epidemiology of brucellosis among cattle in Korea from 2001 to 2011. *Journal of Veterinary Science*, *15*(4), 537-543.

Zhou, K., Wu, B., Pan, H., Paudyal, N., Jiang, J., Zhang, L., & Yue, M. (2020). ONE health approach to address zoonotic brucellosis: a spatiotemporal associations study between animals and humans. *Frontiers in Veterinary Science, 7*, 521.