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Unveiling the Hidden Link of Biosecurity in Preventing Vaccine Failure in Livestock: An Updated Review

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Abstract

The growing global population has amplified the demand for food, making the international trade of livestock a significant threat to animal and public health due to the increased risk of zoonotic disease transmission through animal movement or the consumption of their products. Biosecurity measures (BSMs) and vaccination are two essential tools that, when effectively implemented, can significantly reduce the spread of diseases from livestock. However, their failure not only escalates the burden of disease but also compromises food security and public health. Weak or poorly enforced BSMs can undermine the efficacy of vaccinations, creating challenges against disease prevention efforts. Conversely, robust BSMs such as nutritional and environmental management, routine monitoring of disease, farm management, and hygiene provide a critical foundation for successful vaccination programs by minimizing disease exposure and ensuring vaccine effectiveness. Inappropriate vaccination administration, inadequate cold chain management, and the frequency of immunosuppressive illnesses are also reported as contributing factors to vaccine failure. This review delves into the interconnected roles of BSMs and vaccination, unveiling the importance of the implementation of biosecurity principles in preventing vaccine failure. It also explores how the integration of biosecurity practices and vaccination strengthens animal health systems, mitigates zoonotic risks, and enhances overall food safety. Future research should concentrate on integrated biosecurity techniques by strengthening on-farm biosecurity protocols, proper handling and administration of vaccines, careful disease surveillance, and awareness programs thereby increasing the resilience of our livestock industry against notable diseases.

Keywords: biosecurity measure, vaccination, livestock, challenges, mitigation strategies

1. Introduction

Amidst the globalization of livestock, infectious diseases have become a critical challenge to global industry, with significant implications for food security, economic stability, and rural livelihoods. These diseases not only affect animal productivity but also pose a direct threat to public health, as they often lead to zoonotic infections due to the close interaction between animals and humans (Manuja et al., 2014). For instance, Rift Valley Fever in Kenya resulted in an economic loss of 32 million USD (Perry & Grace, 2009), while Crimean–Congo Hemorrhagic Fever (CCHF) in Pakistan has led to both livestock mortality and human fatalities, highlighting the zoonotic risk posed by such diseases (Masood et al., 2023). Factors such as intensive animal husbandry, climate change, and the escalating threat of antimicrobial resistance (AMR) have further exacerbated the global disease burden (Doeschl-Wilson et al., 2021).

In this context, implementing effective and proactive strategies for disease prevention and control in livestock is paramount to mitigating the global food crisis and safeguarding both human and animal health. Vaccinations along with efficient biosecurity measures are of extreme significance (Nuvey et al., 2023). Vaccination is one of the most cost-effective interventions to safeguard animal health and reduce morbidity and mortality caused by infectious diseases (Roth, 2011). Vaccines stimulate an animal's immune system to generate memory immune cells of B and T lymphocytes capable of recognizing specific pathogens upon secondary exposure to the same pathogen, thereby establishing long-lasting immunity that shields the animal from diseases (Pulendran & Ahmed, 2011).

In addition to vaccination, biosecurity measures (BSMs) have a profound impact on mitigating livestock diseases. BSMs refer to a set of practices designed to prevent the introduction and spread of infectious agents within and between farms, serving as the first line of defense in disease control. Upon effective implementation, both biosecurity measures and vaccination programs work together to enhance disease prevention and control, reducing the overall risk of outbreaks (Layton et al., 2017b). On-farm practices such as maintenance of hygiene and proper sanitation, strict quarantine of new and diseased animals to prevent the spread of infection, and restricted access to the farm effectively reduce the disease burden. Moreover, protection efficiency from vaccination can be tremendously enhanced by ensuring proper administration and handling, cold chain maintenance, and dose optimizations, all of these are considered determinants of biosecurity (Robertson, 2020).

This review examines the synergistic roles of vaccination and biosecurity measures in controlling infectious diseases in livestock. It underscores the repercussions of vaccine failures and weak biosecurity frameworks, using global examples to highlight the need for integrated approaches to disease management. Furthermore, it highlights a critical research gap: the role of efficient biosecurity measures in minimizing vaccine failures and how the absence or improper implementation of these measures can compromise the immunity conferred by vaccines.

2. Threats to the sustainability of the livestock industry

The world is constantly striving to achieve the goals of sustainable development. The provision of clean feed ensuring good health and well-being is of paramount importance. However, the rapid productivity of livestock protein is threatened by the occurrence of diseases as a result of globalization as well as the spread of transboundary infections (Leslie, 2000). The effects of livestock diseases on economic stability, food security, and public health are devastating (Figure 1). According to the FAO (Food and Agriculture Organization), zoonotic diseases contribute to more than 70% of the infections inflicting human beings (Mishra et al., 2021).

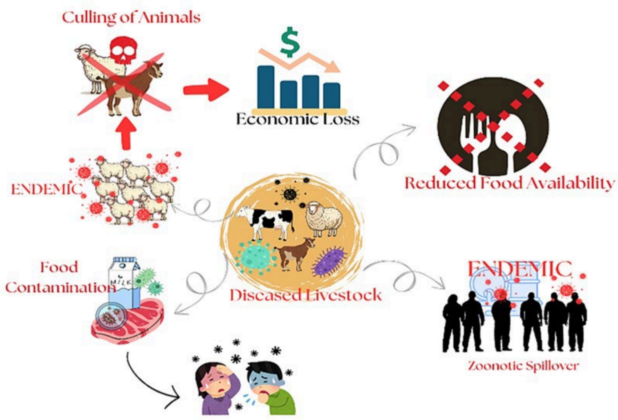

Figure 1. The illustration depicts the various effects of livestock diseases, such as economic losses from culling, decreased food availability, and food contamination. It also emphasizes the dangers of zoonotic spillovers on humans, emphasizing the interdependence of animal health, food security, and public health.

Various livestock species may be the key reservoirs of different zoonotic diseases, posing life-threatening risks to humans (Rodolakis, 2014). The disease spread may occur via a vector, through direct contact, or by contaminated water or food (Ganter, 2015). Such diseases are major constraints on the economic conditions of a region as well as threaten the sustainability of public health. Moreover, to compete in the global market, livestock products must be of higher quality and quantity, and disease-free animal health status is a prerequisite. The sustainability of the livestock industry can be achieved by routine monitoring and surveillance programs to track diseases for various factors (Saminathan et al., 2016).

3. Role of biosecurity measures in livestock

Biosecurity Measures (BSMs) in livestock are the set of comprehensive practices or guidelines implemented to control the introduction, transmission, and development of disease within an animal population. Biosecurity measures are a proactive approach that serves as the cornerstone in promoting the critical aspect of one health. Effective BSMs in livestock prevent the spread of potential contagious infections and zoonotic in a community. Additionally, it provides a barrier to food-borne pathogens from entering the food chain. According to the Food and Agriculture Organization (FAO), biosecurity is the "implementation of measures that reduce the risk of the introduction and spread of disease agents; it requires the adoption of a set of attitudes and behaviors by people to reduce risk in all activities involving domestic, captive/exotic and wild animals and their products" (Huber et al., 2022; Léger et al., 2017) .

Many food-borne diseases can spread from infective animals to humans. In fact, according to the WHO, out of 75% of zoonotic infections, 36% are from animals that are reared for food (Morris et al., 2023). Many zoonotic diseases, including highly pathogenic avian influenza (HPAI), bluetongue virus (BTV), and African swine fever (ASF), pose significant threats to livestock health, food security, and human well-being. For instance, HPAI can rapidly decimate poultry populations, while ASF is a severe hemorrhagic fever of pigs with no vaccine available, leading to devastating mortality rates. Another notable disease, toxoplasmosis caused by *Toxoplasma gondii*, is associated with undercooked meat consumption and exposure to infected animal feces, leading to congenital infections and lifelong health risks in humans. Furthermore, food-borne pathogens such as *Salmonella enterica*, a common cause of enteric diseases in humans, can persist in livestock in a carrier state, shedding bacteria without overt clinical signs, and contaminating food products (Tomley & Shirley, 2009). These examples highlight the urgent need for robust biosecurity measures to mitigate the risks posed by these diseases, safeguard public health, and ensure sustainable livestock production systems.

4. Core biosecurity practices in livestock

Effective biosecurity begins with the development and implementation of a comprehensive plan, starting with the segregation of sick animals to prevent the introduction of potential infections into the farm. This can be done by controlling and monitoring the movement of animals. Measures such as isolating, quarantining, or compartmentalizing new animals for a specified period are crucial to containing potential infections and safeguarding the health of existing herds (Renault et al., 2021).

Strict hygiene practices are equally essential. Regular cleaning of feeding areas, sheds, and vehicles, along with prompt reporting to the national authorities of any signs of disease, are fundamental components. Wearing clean, sanitized uniforms or coveralls, using disinfected equipment, and avoiding shared tools or machinery from other farms further create an unfavorable environment for disease-causing organisms (Morris et al., 2023; Simon-Grifé et al., 2013) .

Periodic health monitoring, screening, and diagnostic testing of vaccination status for new animals introduced to the farm conducted through accredited molecular and microbiological methods enhance biosecurity effectiveness. Preventing close contact between new and existing animals, training farmers on biosecurity practices, and controlling farm access by restricting visitors and vehicles also help minimize the risk of external contamination. Additionally, integrated pest management, which employs chemical, biological, and cultural strategies, plays a vital role in mitigating risks posed by pests and vectors such as rodents, insects, and ticks (Shortall et al., 2017).

5. Prevention: a strong focus on livestock biosecurity

One important aspect of livestock biosecurity is prevention. Most animal disease biosecurity strategies concentrate on prevention as opposed to post-epidemic measures. Moreover, extensive treatment is a burden for farm economics as well. Vaccination is the most successful preventive measure used in the animal sector (Layton et al., 2017a).

5.1. Vaccination as a preventative biosecurity measure

One of the primary objectives of biosecurity measures is to mitigate microbial load. Inadequate biosecurity practices can lead to a high pathogen load, which compromises the immune system and increases the risk of infections, particularly in young livestock during the critical pre-weaning period. Maintaining robust BSMs minimizes pathogen exposure, reduces stress, and ensures healthier animals, creating an optimal environment for a strong immune response to vaccination (Layton et al., 2017b). If the pathogen load in the environment is excessively high (e.g., during outbreaks or in settings with poor biosecurity), it can overwhelm the immunity provided by vaccines, particularly in cases where herd immunity has not been fully established or pathogen exposure is extreme (Crowcroft & Klein, 2018).

Biosecurity practices play a synergistic role in enhancing vaccine efficacy. Discrepancies in BSM such as weak quarantine protocols and the absence of isolation measures for new or sick animals enable the introduction and spread of infectious agents within the herd. In such cases, vaccinated animals are frequently exposed to new or evolving pathogens for which the vaccine may not provide adequate coverage. This is especially critical in diseases where multiple serotypes or strains are prevalent. Studies have shown that despite advances in vaccine development, challenges such as short-lived immunity, and the presence of multiple pathogen strains continue to hinder vaccine success (U Heininger et al., 2012). These limitations underscore the importance of strong biosecurity measures to reduce pathogen exposure and enhance the overall impact of vaccination programs. Additionally, the excessive spread of a pathogen due to ineffective vaccination and control strategies leads to the emergence of new variants, thereby reducing the effectiveness of a specific vaccine. So, targeted and timely vaccination, as a crucial biosecurity determinant, is necessary for developing protective immunity (Stokstad et al., 2020).

Substandard biosecurity plans and management practices, such as overcrowding, inadequate ventilation, and lack of pest control, create stressful environments for livestock. Stress is known to suppress immune function, reducing the ability of animals to mount a robust response to vaccines. Furthermore, stress-induced immunosuppression can exacerbate the impacts of pre-existing diseases, compounding vaccine failure risks (Powell et al., 2011). Together, vaccination and biosecurity form an integrated approach to livestock health, safeguarding animal welfare, economic stability, and public health.

5.2. Role of vaccination in disease prevention

Common viral diseases associated with livestock including infectious bovine rhinotracheitis (IBR), malignant catarrhal fever (MCF), sheep-pox, goat-pox, camel-pox, foot and mouth disease (FMD), bluetongue (BT), Peste-des-petits ruminants (PPR), and bacterial diseases like hemorrhagic septicemia (HS), black quarter (BQ), anthrax, and brucellosis are frequently have the potential to spread across continental borders (Kumar et al., 2015). Ineffective control measures lead to the emergence of new serotypes which in turn pose even greater risk to both livestock and public health. This may be attributed to excess livestock and human population, deforestation, ineffective therapeutic strategies, and lack of public awareness (Chakraborty et al., 2014).

Infectious diseases are dependent on media for their spread in the general population, such as air, water, soil, direct contact, biological and mechanical vectors, etc. The control of carriers involved in the spread of disease is a challenging process, (Raja Sekhara Rao & Naresh Kumar, 2015). Therefore, among the various preventive strategies, vaccination is of paramount importance and is involved in the elimination as well as eradication of various infectious diseases, thereby preserving the sustainability of livestock, poultry, and public health (Bonanni et al., 2014). Vaccines contain attenuated, inactivated, or dead organisms or refined compounds made from them.

5.3. Vaccination failure in livestock

Vaccination is the most efficient and cost-effective method of controlling diseases in livestock. It is significant in safeguarding livestock health, enhancing food security, and ensuring public health safety by reducing the transmission of zoonotic diseases. However, vaccine failures pose significant challenges to achieving these objectives. Vaccine failure is not a singular phenomenon but rather a complex issue influenced by various factors. The causes can range from problems to the vaccine itself (antigen selection, adjuvant use, and formulation) (Al-Kubati et al., 2021; U Heininger et al., 2012) to intrinsic and extrinsic factors to host such as environmental conditions, weak biosecurity measures, or improper administration techniques (Zimmermann & Curtis, 2019) as it is shown in Figure 2. Understanding the underlying causes and consequences of vaccine failures is critical for developing strategies to improve vaccine efficacy and livestock health management.

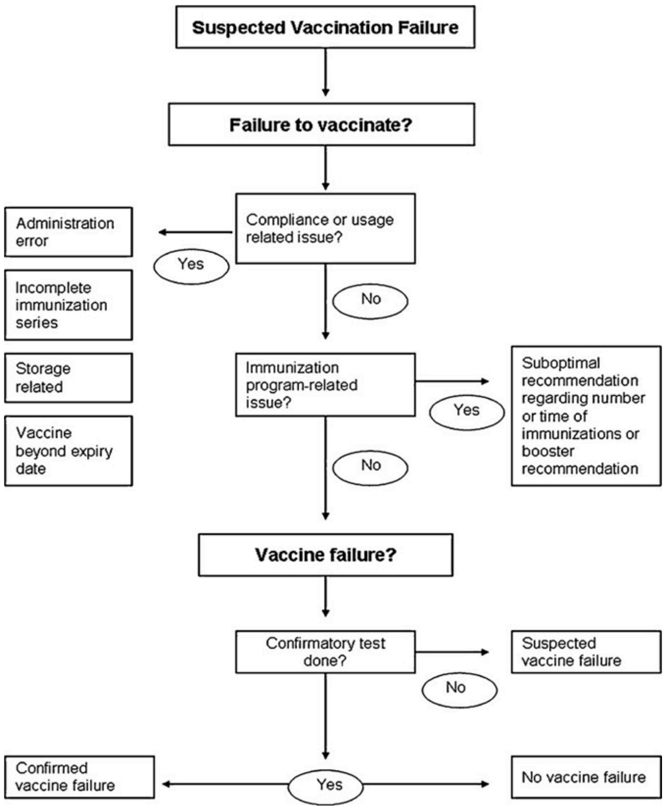

Figure 2. Causes of vaccination failure (U. Heininger et al., 2012).

5.3. Consequences of vaccine failure

Vaccine failures can lead to significant economic losses for farmers and the livestock industry. Unprotected animals are more susceptible to outbreaks, resulting in increased mortality and higher costs associated with disease management programs. As a result, significant economic loss occurs (Hennessy & Marsh, 2021). Vaccine failure also causes a break in herd immunity leading to recurrent infections caused by circulating viruses (Singh et al., 2019). Additionally, vaccine failures cause increased dependence on antibiotics, giving rise to antimicrobial resistance (AMR) (Rosini et al., 2020).

Vaccine failures in livestock have broader implications for public health, particularly in the context of zoonotic diseases. Unvaccinated or insufficiently protected animals can serve as reservoirs for pathogens that may spill over to humans. This risk is particularly high in areas with poor biosecurity practices or close human-animal interactions (Nandi & Allen, 2021). Repeated vaccine failures can erode farmers' trust in vaccination programs, leading to reluctance to adopt future vaccination campaigns. This hesitancy is often compounded by economic pressures and misinformation, creating a cycle of low vaccine uptake and persistent disease outbreaks (Hill et al., 2022).

6. Case studies of disease outbreaks due to vaccine failure and weak BSM

6.1. Foot and mouth disease (FMD) outbreaks

Figure 3 illustrates the mode of transmission of the FMD virus in cattle populations. FMD outbreaks reported in some countries are described below:

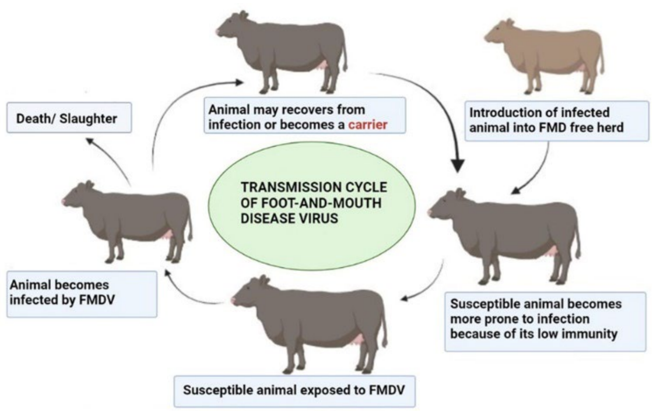

Figure 3. Transmission cycle of FMD virus in cattle (Aslam & Alkheraije, 2023).

6.1.1. Pakistan

Foot-and-mouth disease (FMD), a devastating viral infection that threatens the global livestock sector, can infect animals with cloven hooves. Vaccination plays a crucial role in controlling FMD globally, as it remains one of the most significant diseases affecting livestock. FMD is a highly contagious viral infection having 7 different serotypes (O, A, C, SAT1, SAT2, SAT3, and Asia1) (Admassu et al., 2015). Although Pakistan and more than 100 other nations are still regarded as endemic or occasional zones, the OIE has designated 70 countries as FMD-free zones, regardless of vaccination status. Despite the fact that FMD is already widespread in Pakistan, the prevalence of the disease varies substantially across the country, agroecological zones, and farming methods. Among the seven serotypes, serotype O is most common in Pakistan accounting for almost 72% of all the outbreaks, followed by serotype A (19.5%) while serotype C has not been detected in Pakistan since 1983. In a study conducted for outbreak investigations of FMD (n=64) in nine districts of Punjab province, data on several potentially related characteristics were gathered using a standardized questionnaire. Beginning in January, the FMD epidemics peaked in February (n = 36, 56.25%), and then stopped in April 2019. O was the most common serotype (45.83%), which was followed by Asia-1 (29.17%) and A (13.89%), although several farms had mixed infection with serotypes A and O (9.72%) and O and Asia-1 (1.39%). The distance between the farm and a nearby livestock farm, the history of adding a new animal to the herd whose FMD vaccination status was unknown, the absence of routine FMD vaccination, the history of an animal broker visit, and the size of the herd were all found to be significantly associated with the occurrence of FMD outbreaks in Punjab province in 2019, according to multivariable analysis. Summing up, the incidence of FMD on Pakistani livestock farms can be considerably decreased by enhancing biosecurity protocols, preventing the introduction of new animals without a history of FMD vaccination, and regularly administering the appropriate serotype vaccines against the disease (Ali et al., 2022).

6.1.2. South Korea (2010-2011)

The FMD epidemic in South Korea in 2010 presented substantial challenges due to delays in accurately diagnosing the disease in pigs. Early detection and reporting, a key biosecurity measure, relies on molecular or microbiological diagnostic tests such as ELISA kits. However, this study highlights critical lapses during the outbreak, where misdiagnosis and false-negative results delayed reporting to the government by one week. Ultimately, accurate results were obtained, but the delay exacerbated the spread of the serotype O virus. The outbreak had a huge economic impact, including approximately 3,700 farms, leading to the culling of 3.48 million susceptible animals, underscoring the importance of robust diagnostic protocols in disease control (Park et al., 2013).

6.2. Peste des petits ruminants (PPR) outbreaks in Asia

There are four lineages of PPRV strains: I, II, III, and IV, although phylogenetic analysis based on partial N or F gene sequences divides PPRV into a single serotype. At the moment, Lineage IV is most common in Asian countries (Ahaduzzaman & Science, 2020). Sheep and goats are the primary species affected by PPR (Albina et al., 2013). Pakistan reports 80–90% morbidity and 50–80% mortality from virus infection (Chauhan & Singh, 2020). FAO figures show that between 2012 and 2017, the annual output losses of South Asian countries due to PPR rose to $2972.5 million (Ismail et al., 2020).

A meta-analysis conducted by an author in 2020 depicted the combined prevalence of 43.55% of PPR in Pakistan. However, the present analysis from 2004-2023 depicted the high prevalence rate of PPR in small ruminants all over Pakistan. According to the random effects meta-analysis, 51% of sheep and goats had a pooled prevalence of PPR (Zafar et al., 2024). The results of the survey also revealed that, within the given geographic area, the prevalence of PPR, despite vaccinations, was 61% in Sindh, 54% in Punjab, 51% in Baluchistan, 51% in Gilgit-Baltistan and Azad Jammu and Kashmir, and 44% in Khyber Pakhtunkhwa (Zafar et al., 2024). One possible reason for the widespread occurrence of PPR in sheep and goats is the interprovincial movement of diseased animals without proper quarantine precautions. Therefore, the implementation of appropriate control measures as well as preliminary precautions are essential for the control of PPR in Pakistan.

6.3. Lumpy skin disease (LSD) outbreak in Asia

Lumpy skin disease (LSD) is a vector-borne disease of cattle and water buffalo caused by the Capripoxvirus virus (LSDV). The possible mechanisms of transfer of the LSD virus are depicted in Figure 4. The first LSD case was recorded in Zambia in 1929. It was endemic in Africa until 1985, when it migrated to Eastern Europe and Asia (Gupta et al., 2020). The most recent outbreak of LSD was observed in the Asia-Pacific area. LSDV, a contagious bovine illness, has also produced a substantial outbreak in Pakistan. In 2024, LSDV was rapidly spreading in many cities across Pakistan due to a lack of resources in farming communities and limited access to effective vaccines in affected regions. The disease has caused significant losses in the livestock industry (Hussain et al., 2024). Authorities are currently developing biosafety measures to combat LSD, including controls on animal movement, vectors, and animal products (Afzal et al., 2024).

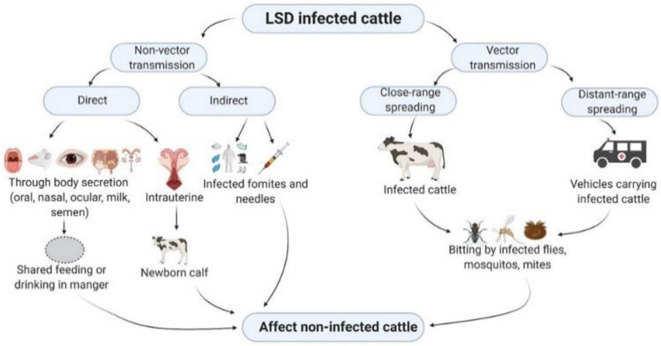

Figure 4. Methods of transmission of LSD virus (Das et al., 2021).

6.4. Avian Influenza (AI) outbreaks in poultry

Avian influenza viruses (AIV) are type A influenza viruses belonging to the Orthomyxoviridae family that use single-stranded RNA with negative polarity as their genetic material. AI viruses are divided into two types based on their disease-causing ability; highly pathogenic avian influenza (HPAI) viruses and low pathogenic avian influenza (LPAI). H5 and H7 are termed HPAI, while H9 and some strains of H5 and H7 are classified as LPAI. The LPAI is a constant source of economic damage in the poultry business globally. Poultry producers suffer huge losses each year as a result of insufficient egg production, poor weight gain, and mortality (Khan et al., 2023).

A study on H9N2 avian influenza viruses suggested that the virus evolved into various antigenic groups due to antigenic drift, resulting in pathogenicity and immunization failure, even with vaccination (Shahzad et al., 2020). A study that evaluated the vaccine quality of four secretly traded H5 and H9 avian influenza vaccines in Nigeria suggested the lack of hemagglutinating and PCR-detectable influenza antigens. This infers that all those vaccines lacked AI antigen and therefore could not induce any form of protection in vaccinated subjects (Oluwadare et al., 2024).

6.5. Infectious bronchitis outbreaks in poultry

Infectious bronchitis (IB) is a globally prevalent disease with a significant economic impact. The inability of virus strains to provide cross-protection against field IBV strains poses a significant risk to the chicken sector in Pakistan, which is already in financial distress. A study showed that a total of 388-layer samples from 61 farms were tested for IB, with 68 (17.5%) positive for IBV against 4/91 antigen and 184 (47.42%) positive against M-41 antigen. ELISA detected 98.48% of 1843 layer samples as positive, whereas 148 (42.80%) of 346 broiler samples tested positive. The study found a high prevalence of IB in poultry, resulting in ongoing disease outbreaks despite immunization efforts (Fayyaz et al., 2023).

6.6. Brucellosis outbreaks in ruminants

Brucellosis, a zoonotic disease, is a significant public health concern in many countries. It primarily affects ruminants, causing abortions by infecting the placenta. The disease also contaminates milk and other animal products, serving as a transmission route to humans upon consumption (Figure 5). Studies suggest that neighboring countries such as Iran, Syria, and Greece, where brucellosis is prevalent, significantly contribute to its spread in Turkey. This is primarily due to weak biosecurity measures in transboundary livestock movement and a lack of commitment to implementing effective control strategies, which collectively intensify the public health and economic burden in the region (Akar et al., 2024; Yumuk & O'Callaghan, 2012). Furthermore, studies have shown that outbreaks are frequent in winter when animals are crowded in their sheds, due to which transmission becomes higher. The inadequate training and awareness among farmers, combined with ineffective vaccination plans, make disease control challenging and are key factors behind the recurring outbreaks (Demeli & Fındık, 2021).

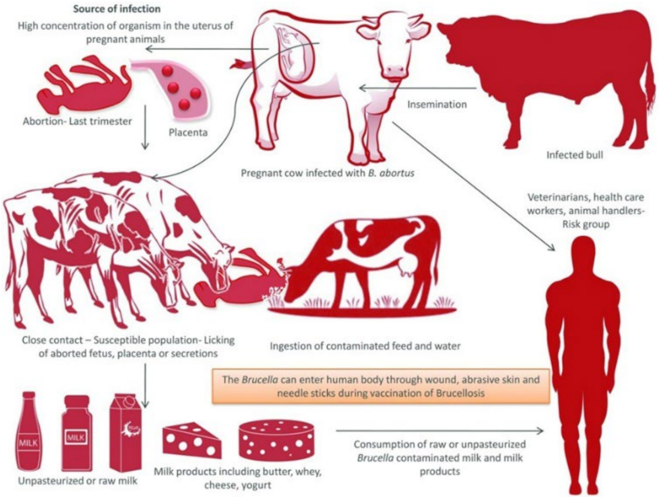

Figure 5. The zoonotic transmission cycle of bovine brucellosis. Courtesy: (Khurana et al., 2021).

7. Challenges in implementing biosecurity

Farmers often describe doing their best to control on-farm biosecurity, even if their actions do not correspond with the objectives of authorities. Factors influencing farm performance include physical and economic constraints, socio-demographics, attitudes toward animal health and biosecurity, and access to information.

7.1. Economic constraints

The decision of Individual farmers to apply biosecurity measures is generally attributed to economic constraints, especially in low-income settings. Niemi et al. (2016) investigated how the characteristics of livestock producers and farms, as well as the perceived costs of biosecurity, relate to the adoption of biosecurity measures across Finland. The findings indicated that the costs of adopting proper biosecurity measures are a major constraint for the implementation of these measures. If the perceived costs are too high, producers may choose not to implement the measures.

7.2. Awareness and compliance of farmers

Adoption of biosecurity measures is inadequate due to structural restrictions in mountain farms and farmers' awareness gaps (Zanon et al., 2024). Thus, specific approaches and educational programs are critical for empowering farmers and promoting optimal practices in biosecurity and animal welfare management. According to Correia-Gomes et al. (2017), small-scale farmers have lower levels of awareness of biosecurity practices than larger operations. Additionally, farmers frequently regard certain biosecurity measures as impractical due to the logistical burdens associated with their implementation in day-to-day operations.

7.3. Gaps in policy enforcement and veterinary services

Several studies suggest that the causes for the poor adoption of the recommended BSMs may originate from the difference in the perspective and goals existing between the authorities, veterinarians, and cattle farmers. These differences frequently result in the perception of weak or inadequate public biosecurity policy. Cattle farmers may be uninterested in communication due to differences in communication objectives, and as a result, they may not comprehend the information or seek more direction. Therefore, despite variations in disease management objectives, animal health authorities and livestock farmers could achieve an agreement on determining priority BSM (Renault et al., 2021).

8. Mitigation strategies and recommendations

8.1. Preliminary detection and disease surveillance

Timely reporting of unusual disease symptoms is essential for an effective government response because delays in diagnosis can be quite expensive (Carpenter et al., 2011). Strong ties between animal producers, agribusiness groups, regulatory bodies at different governmental levels, and veterinarians are crucial for both identifying an outbreak and implementing a prompt and efficient response (Wright et al., 2018). Moreover, the delay between the disease introduction and disease detection is a major contributor to the dissemination of a pathogen if appropriate control strategies are not implemented (Gates et al., 2021).

The adoption of passive surveillance programs is a crucial tool for disease control. Such programs usually make use of already-existing electronically recorded animal health data streams, such as animal production records, diagnostic laboratory submissions, veterinary medical records, and abattoir inspections. Regularly investigating reported clinical illness occurrences is another aspect of passive surveillance. For example, farmers and veterinarians may use telephone hotlines to alert animal health authorities about potential disease invasions. The main benefit of passive monitoring programs is that they eliminate many of the challenges because they don't need additional effort from data sources (Gates et al., 2021).

8.2. Improving vaccine delivery

Veterinary vaccines play a crucial role in preventing and controlling livestock diseases worldwide. Proper training for those involved in vaccination, storage, and handling is necessary to ensure vaccine potency and effectiveness. Effective livestock management approaches, such as proper vaccination and controlling animal movement from endemic locations, might help manage disease risk. Cooperative initiatives including national and state governments play a key role in achieving the country's aim of declaring as a disease-free zone. Preventive immunization has very been effective in several South American nations in both controlling and eliminating the illness. As a result, improving vaccines should be the top priority in livestock research. The early use of a highly potent vaccine in the early stages of an outbreak might minimize viral shedding and limit disease transmissions (Yohannes et al., 2020).

8.3. Strengthening biosecurity

Tick and pest control, vaccination, movement controls, quarantine of newly introduced animals, culling of diseased animals, feed management, facility, and vehicle maintenance, protocols for handling and treating infected animals or contaminated products, animal hygiene, sanitation, limitations on sharing, disinfection procedures for equipment, vehicles, and facilities, and protocols for handling manure and disposing of carcasses are all included in the farm biosecurity measures. Farmers who raise livestock may gain profit from the ongoing applications of biosecurity on their farms. A strong biosecurity program decreases the costs of disease treatment and helps to ensure the production of safe, nutrient-dense, high-quality products which increases the likelihood of operating a profitable business. It also acts as the first line of defense by detecting diseases early and limiting their spread within the farm. When biosecurity measures are implemented to restrict infectious illnesses in livestock, they not only safeguard animal health and its economic advantages, but they also directly lower the danger of zoonotic pathogen transfer to people (Msimang et al., 2022). Resources for biosecurity in small-scale farming are quite few and might be difficult to locate. In addition to the resources for young people, both governmental and private organizations are crucial in providing biosecurity resources (Morris et al., 2023).

8.4. Integrated approach

The significance of biosecurity and vaccination has been extensively documented in the literature, but the relationship between the two is rarely discussed. Integrating vaccination programs with biosecurity education campaigns has proven beneficial in boosting livestock health and minimizing disease outbreaks. A study on loss prevention revealed the strategies used by hog producers to prevent potential losses and outlined the relationship between hog insurance, immunization, and biosecurity procedures. It demonstrated how biosecurity procedures support the use of high-quality vaccinations (Zhang et al., 2013).

9. Conclusion and Future Perspectives

The integration of vaccination and biosecurity is the proper way of controlling livestock diseases. Herd immunity is enhanced by vaccination resulting in reduced incidence of diseases and hence reduced costs. Biosecurity measures, however, are the first line of defense in keeping pathogens out of the flock or minimizing their spread. These methods are mutually supportive as vaccination decreases the consequences of the disease spread, while biosecurity increases the effectiveness of vaccination programs by limiting pathogen contact. However, the effectiveness of this integrated approach relies on the correct training, surveillance, and application of the best practices by livestock producers and veterinarians. Future work should focus on enhancing vaccination regimes, specific biosecurity measures for different livestock production systems, and the creation of new technologies for the detection of diseases. When vaccination and biosecurity are combined, they will not only maintain animal health but also produce optimal agricultural productivity. In the fight against zoonotic diseases and for the overall health of livestock, strengthening the connection between vaccination and biosecurity is crucial. This approach will also benefit the public health sector through lower human health risks, which is essential for global health security. Thus, investment in vaccination and biosecurity should be considered not only a cost but also a return on investment, leading to long-term growth and sustainability in livestock farming.

Conflict of interest

The authors of this manuscript declare no conflict of interest.

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