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EPIDEMIOLOGICAL INSIGHTS AND PUBLIC HEALTH IMPLICATIONS OF ZOONOTIC BOVINE SALMONELLOSIS

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ABSTRACT

Bovine salmonellosis is a highly pathogenic food-borne zoonotic disease. The etiological agent of bovine salmonellosis is *Salmonella enterica* subsp. *enterica* serovar Dublin (*S.* Dublin). *S.* Dublin is a highly resistant pathogen that can survive in the harsh conditions of the host and the environment. Bovine salmonellosis poses a significant threat to the economic losses and public health. *S.* Dublin causes serious health problems, including septicemia, enteritis, and abortion. Bovine salmonellosis is highly prevalent in young calves, causing significant mortality. Beyond its impact on animal health, salmonellosis causes severe economic losses. Multiple factors contribute to the economic losses, including treatment costs, a decline in milk production, and a high risk of outbreaks in the herd. There are multiple routes for the transmission of *S.* Dublin, including contaminated water, feed, fecal material, and the environment. However, fecal material contaminated with *S.* Dublin pathogens is considered a primary route for transmission. The pathogenesis of bovine salmonellosis includes highly complex patterns of pathogen and host interactions. To control bovine salmonellosis, it is a need to understand the epidemiological aspects and develop effective control strategies. This review highlights the public health and economic significance of bovine salmonellosis, its clinical manifestations, and diagnostic tools for identification and eradication.

Keywords: Salmonellosis, *S.* Dublin, Zoonotic, Food-borne, Epidemiology, Public health

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1. INTRODUCTION

Salmonellosis is a zoonotic disease that causes significant human health disorders and affects a variety of animal types and species, especially bovines (Chlebicz and Śliżewska 2018). *Salmonella enterica* subsp. *enterica* serovar Dublin (*S.* Dublin) is the etiological agent of bovine salmonellosis (García-Soto et al. 2021). *S.* Dublin is a non-spore-forming, oxidase-negative, Gram-negative, motile bacterium belonging to the family Enterobacteriaceae (Powell et al. 2024). *S.* Dublin survival is influenced by various factors, including pH, temperature, and competing microflora (Petrin et al., 2022). *S.* Dublin can remain cocooned for long years in dried fecal materials and months in organic substrates, such as soil, manure, and slurry (Silva et al. 2025). Although it is resilient, S. Dublin is sensitive to sunlight, disinfectants, and various antibiotics (McCarthy et al., 2021). Nevertheless, it can be reported the occurrence of multidrug-resistant strains in both the dairy and beef production systems (do Amarante et al. 2025) can be reported. Favorable temperature and humidity can permit *S.* Dublin to increase extracellularly (Pulavarty et al. 2021). In cattle, salmonellosis induces a serious clinical condition, which is mainly characterized by enteritis and septicemia (Galán-Relaño et al. 2023). The additional indicators are fever, dysentery, and abortion in pregnant animals (Mori et al. 2021). Manifestation and virulence of the disease are the result of multiple factors, including host age, infectious dose, immunological status, and physiological condition (Lamichhane et al. 2024). The most common combination of septicemia and enteritis influences the lives of neonatal calves; however, pneumonia and neurological signs may also be observed (Robi et al. 2024). In calves aged more than one week, the acute type of enteritis predominates and is not accompanied by systemic complications (Kostanić 2024). Bovine salmonellosis is initially characterized by high temperature (40.5-41.5°C) and then dysentery and sometimes tenesmus (Almuzaini and Alajaji 2025). Mortality rates in both neonatal and young calves can reach up to 100%, depending on bacterial

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virulence and infection dose (Mee et al. 2021). In lactating cows, infection is often associated with reduced milk yield (Asefa et al. 2023).

S. Dublin is most frequently transmitted through ingestion of contaminated feed, water, or exposure to a polluted environment (Nolan et al. 2023). The severity of infection is influenced largely by the infectious dose (Velasquez-Munoz et al. 2024). Following entry, *Salmonella* colonizes the intestinal tract of the host and subsequently invades columnar enterocytes via the lymphatic system (Li 2022). The pathogen also penetrates macrophages, which normally serve as a key defence barrier (Taban et al. 2022). Within macrophages, *S.* Dublin can survive and replicate, facilitating dissemination through the bloodstream and lymphatic circulation to multiple organs, including the lungs, liver, spleen, tonsils, and lymph nodes (Ijaz et al. 2021). A characteristic feature of *S.* Dublin is its ability to establish latent carriers within herds, perpetuating the infection cycle (Nielsen et al. 2004). In some cases, *S.* Dublin can be isolated from internal organs of apparently healthy animals that show no clinical signs (Bhattacharjee et al. 2022).

Several clinical and carrier states of bovine salmonellosis have been described, including per-acute, acute, chronic, passive carrier, active carrier, and latent carrier forms (Almuzaini and Alajaji 2025). Shedding of the pathogen may or may not occur at these stages. *S.* Dublin can be shed via urine, saliva, milk, Feces, and vaginal secretions (Foster et al. 2021). The duration and magnitude of bacterial shedding differ among animals, with Feces being the most significant source because of the high bacterial load present (Mkangara 2023). Consequently, the fecal–oral route is recognized as the primary mode of transmission. The immune response to *S.* Dublin involves a coordinated action of innate and adaptive mechanisms (Martinez-Sanguiné et al. 2021). The initial defence is mediated by neutrophils, polymorphonuclear leukocytes, macrophages, natural killer cells, and their associated cytokines (Tsai et al. 2021). This non-specific response subsequently triggers the adaptive immune system. Following infection, IgG and IgM levels rise, with IgG reaching peak concentrations approximately 6–11 weeks after exposure (Santamaria et al. 2024). Although *S.* Dublin is considered host-adapted to cattle, the precise mechanisms underlying this adaptation remain poorly understood (Stevens and Kingsley 2021).

Understanding the precise mechanisms of host adaptation in *S.* Dublin is beyond the scope of this review. What remains more critical is recognizing how the pathogen interacts with its bovine host, as this knowledge provides a basis for designing effective control programs that do not necessarily involve other livestock sectors (Doeschl-Wilson 2011). Prevention strategies play a key role in limiting the spread of infection (Sánchez-Vargas et al. 2011). This review highlights the pathogenesis, epidemiological features, and public health significance of *S.* Dublin, with the aim of supporting improved preventive and control measures. In addition, we briefly address the economic impact, clinical presentation, diagnostic approaches, and overall public health importance of bovine salmonellosis caused by *S.* Dublin.

2. BOVINE SALMONELLOSIS ECONOMICS, ANTIMICROBIAL RESISTANCE, AND ZOONOSIS ASPECTS

2.1. Economic Burden

Salmonellosis is responsible for considerable financial losses in livestock production, largely because of the burden of clinical disease (Sanni et al. 2023). Expenses arise from veterinary diagnosis, treatment, laboratory testing, use of disinfectants, biosecurity measures, and in many cases, mortality among affected animals (Clemmons et al. 2021). Additional losses are linked to reduced milk yield in dairy cattle, impaired weight gain, and in severe infections, abortion and reproductive failure (Szelényi et al. 2023). In large herds, the detection of a single positive case presents a major challenge, as it becomes costly and labor-intensive to determine the infection status of all animals, thereby increasing reliance on diagnostic testing and preventive programs (Forshell and Wierup 2006). The financial burden of bovine salmonellosis has been estimated in billions of dollars annually in the United States, millions of pounds in the United Kingdom, and approximately $160 million in Canada (Yada 2023). Reports from North America further indicate that the economic toll of individual outbreaks may range from $36,400 to as high as $62 million. Economic assessments suggest that for every £1 invested in surveillance and control strategies, nearly £5 can be saved, underlining the value of effective prevention (Almuzaini and Alajaji 2025).

2.2. Antimicrobial Resistance (AMR) Concerns and Zoonotic Aspects of *S.* Dublin

Antimicrobial resistance (AMR) is one of the most acute global health problems, and zoonotic bovine salmonellosis caused by *Salmonella enterica* serovar Dublin is a severe contributor to this rising issue (Kenney et al. 2025). Traditionally, tetracyclines, aminoglycosides, sulphonamides, and fluoroquinolones, among other antibiotics, were used in rearing cattle as a control mechanism against salmonellosis and other bacterial diseases (Abreu et al. 2023). Nevertheless, inappropriate use and excessive intake of these medications in prophylaxis and treatment have led to the development of multidrug-resistant (MDR) *Salmonella* strains (Bello et al. 2024). These

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resistant isolates do not only undermine the effectiveness of veterinary medication but also present a significant zoonotic risk (Caneschi et al. 2023). Direct contact with an animal, in addition to contaminated food products or the environment, can result in the infection being triggered in human beings (Sebola et al. 2023). There is also growing resistance in *S*. Dublin to drugs that are among the last line of defence in humans, such as extended-spectrum cephalosporins and fluoroquinolones (Ali et al. 2025). The resistance is especially concerning since it restricts treatment choices against severe human infections, particularly in vulnerable situations like that of children and older adults, as well as the immunocompromised (Theodorakis et al. 2024). The horizontal gene transfer of resistance by mobile genetic elements, including those encoding the extended-spectrum β-lactamases (ESBLs) contributes to the rapid spread of AMR among the bacterial species (Shropshire et al. 2022).

The effects of antimicrobial resistance in bovine salmonellosis act in multiple dimensions (Aworh et al. 2024). Infections are harder to treat in bovines and much costlier to do so, lengthening the duration of disability and raising morbidity and mortality rates of infected herds. In public health perspective, resistant *Salmonella* strains that enter the food chain compromise the food safety of animal-based products, which include milk, beef, and dairy products (Mthembu et al. 2021). In addition, resistant strains can remain in the environment, which poses new reservoirs of infection that are difficult to eradicate.

2.3. Clinical Features

S. Dublin is commonly maintained in bovine herds in an endemic state, with cattle serving as the primary reservoir of infection (Bentum et al. 2025). Infected animals may carry the pathogen for extended periods, and in some cases, persistence may last for the lifetime of the host (Ehrhardt et al. 2023). Clinical disease in calves typically becomes evident between 2 and 6 weeks of age, with severity influenced by the infectious dose (Berber et al. 2021). In young calves, the disease often appears in an enteric form, initially presenting with dullness, fever, and loss of appetite, which then progresses to profuse diarrhea (Reddy et al. 2024). Feces may contain blood and become stringy due to sloughed intestinal mucosa (Baumgartner 2021). In adult cattle, subacute or acute forms are more common, and pregnant animals may abort during the early stages of enteric disease (Kuria 2023). Severely affected animals frequently show fever, anorexia, and depression. Other notable signs include reduced milk yield, foul-smelling diarrhea, bloody and mucoid Feces, dehydration, and congested mucous membranes, often accompanied by shreds of necrotic intestinal lining (Van et al. 2009). Retained placenta is another frequent complication, reported in up to 70% of cases. While the acute phase of bovine salmonellosis may last only about a week, postmortem findings vary considerably depending on the stage and severity of infection (Velasquez-Munoz et al. 2024).

In animals that succumb during the per-acute stage of infection, postmortem examination may reveal no obvious gross lesions (Wilson et al. 2022). However, in most cases, petechial hemorrhages are observed within the sub-serosal and submucosal layers. In young calves, the mesenteric lymph nodes are typically enlarged, congested, and edematous, while the small intestine often shows muco-hemorrhagic or diffuse mucoid enteritis. In adult cattle, necrotic enteritis is more frequently observed, particularly affecting the large intestine and ileum (Goossens et al. 2017). The spleen and mesenteric lymph nodes are enlarged and edematous (Molossi et al. 2021). The intestinal wall becomes markedly thickened and is frequently covered with grey-yellow necrotic material, which overlies a granular, reddened mucosal surface (Taylor et al. 2004).

2.4. Pathophysiology of *S*. Dublin

S. Dublin infection may have a series of stages, which include per-acute, acute, chronic, passive carrier, active carrier, and the latent carrier ones (Husnain et al. 2024). The per-acute stage is often fatal in animals, with symptoms developing very briefly, sometimes before the animals can produce bacterial shedding, within 1-2 days (Narayan et al. 2023). The acute stage could last 1-2 weeks and in others up to 5-9 weeks. Animals also expel very high numbers of bacteria at one time or at intervals of time through their Feces, urine, milk and vaginal secretions. Published bacterial loads in the acute phase vary between 1 and 10^8 CFU/g of Feces (Walker et al. 2023). Chronic infections may last for several months, with shedding that may be absent, continuous, or intermittent. Carrier states, including passive, active, and latent carriers, may persist from weeks to several years. In these cases, bacterial excretion varies in pattern and intensity, with levels classified as low (10^1–10^4 CFU/g Feces), moderate (10^4–10^5 CFU/g Feces), or high (>10^5 CFU/g Feces), depending on the infectious dose and host–pathogen interactions (Ibekwe et al. 2002).

In cattle, *S*. Dublin infection usually begins with ingestion of contaminated feed or water (Koyun et al. 2023; Bentum et al. 2025). Once inside the host, the bacteria pass through the rumen and stomach, where they encounter acidic conditions and competing microflora (Welch et al. 2022). To survive, *S*. Dublin has developed adaptations that allow it to resist gastric acid and overcome the resident microbial population (Helmy et al. 2023). Subsequently, the pathogen colonizes the intestinal epithelium. In the intestine, normal motility and mucus secretions act as host defences, but *S*. Dublin possesses fimbriae and lipopolysaccharides that enable it to adhere to

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and bypass these barriers (Zhou et al. 2023). When the pathogen breaches these defences, neutrophils and macrophages are recruited to the site of infection (Pidwill et al. 2021). *S.* Dublin counters this immune response by releasing effector proteins via Type III secretion systems (TTSS-1 and TTSS-2), which allow it to resist phagocytic killing (Schadich et al. 2016). Once the immune defences are subdued, the bacteria disseminate systemically, leading to the development of enteritis (Iacob et al. 2019). Systemic infection is typically associated with pyrexia as part of the host's inflammatory response (Sierawska et al. 2022) (Fig. 1).

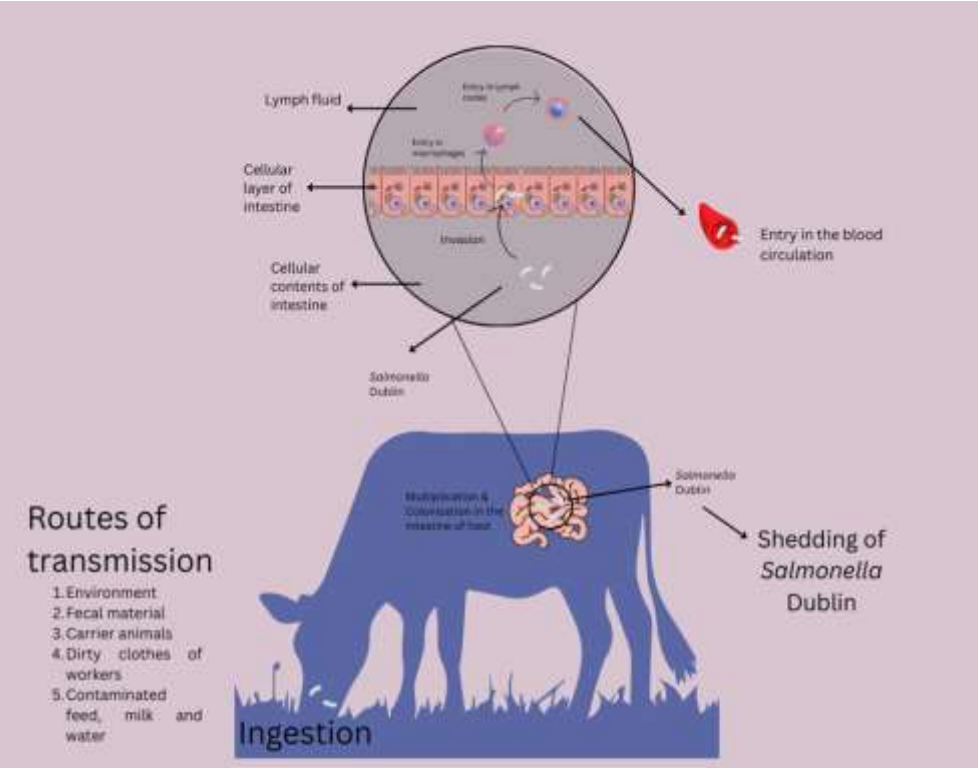

Fig. 1: Pathogenesis of bovine salmonellosis.

2.5. Public Health Implications

Salmonellosis remains a major public health issue worldwide, responsible for significant levels of morbidity and mortality (Nazir et al. 2025). While most human infections are moderate and self-limiting, severe cases can progress to fatal outcomes. Globally, salmonellosis is estimated to cause more than 3 million human deaths annually. In the United States alone, approximately 2–4 million cases are reported each year, with 500–1000 of these resulting in death (Galán-Relaño et al. 2023). Despite advances in hygiene, education, and food processing practices, salmonellosis continues to present a serious public health challenge (Mkangara 2023). In Ireland, no more than 10 people are infected with *S.* Dublin per year (Glynn et al. 2025). Bovine salmonellosis is attributed as one of the most targeted public health issues of Ireland because of threat to both livestock and human beings because of genetic modification of *S.* Dublin (Pedersen et al. 2023). The evolution of *S.* Dublin has implied new changes in genetic examinations, such as multi-locus enzyme typing and fliC flagellin DNA sequencing, which indicates that changes have occurred in the recent past (Jurado-Martín et al. 2021). It is suggested to be closely related to the widely occurring serotype *S. enteritidis*, which causes infections in poultry and humans, where the two differ by only minor genetic elements (Li et al. 2021). When *S.* Dublin has become established in a cattle herd, the presence of carrier animals is an ongoing threat, since infected cows can remain infected and contagious during the rest of their lives (Lamichhane et al. 2024). Various diagnostic approaches can be used in diagnosing bovine salmonellosis at a herd level and are presented below:

2.6. Diagnostic Approaches

Accurate diagnosis is crucial for reducing economic losses and protecting the health of cattle herds affected by salmonellosis (Mohammed 2025; Zhengtian et al. 2025). To be considered definite, no reliance on only pathological changes, postmortem changes, or clinical manifestation can be made in the definitive diagnosis (Almuzaini and Alajaji 2025). Instead, it is necessary to use certain diagnostic methods, such as an attempt to grow bacterial cultivation, clinical examination, and the presence of antibodies to *S.* Dublin (Neupane et al. 2021; Henderson et al.

2022). The pathogen is identified using conventional culture methods using Feces, tissues, and fluid and environmental samples (Loderstädt et al. 2021; Kabiraz et al. 2023). The significant benefit of using culture-based techniques is that they can be used in large herds or to identify the origin of the infection in case of an outbreak investigation, although these methods are not that sensitive (Jenkins and Bean 2023; Islam et al. 2025). Molecular methods, particularly polymerase chain reaction (PCR), have emerged as powerful alternatives (Gow et al. 2022; Kreitmann et al. 2023). PCR assays offer superior sensitivity and rapid detection, though they do not always allow subsequent serotyping or strain characterization (Jiemsup et al. 2025; Malik et al. 2025). The principal diagnostic approaches for bovine salmonellosis are outlined below:

2.6.1. Conventional Culture Approaches: Culture-based methods are widely used for the isolation of live bacteria from samples and involve a stepwise procedure consisting of pre-enrichment, selective enrichment, plating, and final confirmation (Sohrabi et al. 2022; Elbehiry et al. 2023). Successful detection requires the bacteria to survive and multiply during the enrichment stages (Mi et al. 2022). Ideally, this approach should be capable of detecting as few as a single colony-forming unit (CFU) in a sample, although this sensitivity is not always achieved in practice (Bhuyan et al. 2023). For fecal samples of *S.* Dublin, the specificity of culture is considered as 100%, but the sensitivity remains suboptimal (Sekhwal et al. 2025). To improve detection, especially for identifying active carriers, repeated fecal culturing is recommended, as this increases the likelihood of isolating the pathogen (Sadaqa et al. 2025).

2.6.2. Genetic Diagnostic Approaches: PCR-based tests are well known as more accurate in identifying *S.* Dublin in biological samples than performed by culture methods (Gow et al. 2022; Liu et al. 2024). The mechanisms of PCR-based methods are based on the recognition of certain fragments of bacterial genetic material (Zhang et al. 2021; Huang et al. 2024). The most popular approaches that may be used are conventional PCR and real-time PCR (Xin et al. 2021). Conventional PCR offers only a qualitative outcome, which only tells the state of presence or absence of a target organism, but real-time PCR is quantitative, which enables the number of copies of a target organism to be measured at each cycle with the help of computer-based mechanisms (Gupta et al. 2023). The effectiveness of internal controls and the reliability of results in PCR application depend mainly on the degree of efficacy of primers, probes, etc. (Artika et al. 2022). A drawback with the PCR technique is that the serovar of *Salmonella* is not identified; thus, culture-based confirmation is still necessitated in case serotype determination is needed (Neyaz et al. 2024). It has been reported that the performance in tests could be inconsistent because the specificity and sensitivity of PCR are not always optimal (Hellou et al. 2021). In naturally affected cattle, real-time PCR has also shown a low sensitivity compared to conventional bacteriological culture methods, highlighting the ongoing diagnostic potentiality of bacteriological culture (Abd El-Aziz et al. 2021).

2.6.3. Immunological Detection Approaches: Antibody detection via serology has also shown to be a useful method of detecting current and previous infection with *S.* Dublin (Um et al. 2023). ELISA (Enzymatic-Linked immunosorbent assay) is highly applicable in detecting *S.* Dublin O-antigens in milk and serum (Um et al. 2022). The method is used to describe the level of a humoral immune response, which allows determining the presence of ongoing infection and previous infection (Lagousi et al. 2021; Paul et al. 2023). After exposure, the level of IgG antibodies in the body usually increased to a detectable range after one to several weeks (Bayart et al. 2021). Among the strengths of ELISA are its comparatively low cost, ease of sample collection, and that it can be used on large-scale testing (Albiero et al. 2024). Because of its advantages, ELISA is extensively used in monitoring the herd levels, evaluating control problems, and helping in disease control administrative choices (Hernandez-Medrano et al. 2021; Hurri et al. 2022). Equally in Denmark, routine sampling of bulk milk is implemented regularly whether it be every other day to capture *S.* Dublin and other infectious agents like infectious bovine rhinotracheitis (IBR) and bovine viral diarrhea virus (BVDv) (Nielsen et al. 2021). Such systematic surveillance facilitates the use of effective control measures (Zubaydi et al. 2023). There is also standard ELISA utilizing serum, which is sensitive as an individual milk ELISA (Chen et al. 2024). However, to further categorize strains, more sophisticated molecular and genomic tools are necessary; their description is beyond the scope of this review.

2.7. Prevention and Control Strategies

Effective prevention and control of zoonotic bovine salmonellosis can only be achieved using a multidimensional strategy since the disease is highly complex in nature and can be transmitted directly or through contaminated animal products, water or feed (Sharan et al. 2023). Multi-faceted approaches involving a combination of biosecurity precautions, vaccination, farm management systems, and food safety interventions, all with one health approach, are effective (Qureshi et al. 2023). The basis of prevention at the farm level is biosecurity. Regulation, including restriction of animal movement, quarantining farm livestock that are brought onto the farm, ensuring cleanliness of housing and equipment, and limitation of access by outside visitors, effectively minimizes risk of entry of *Salmonella* into a livestock group. Feeding practices also are critical, and using clean feed and water sources, preventing feed contamination with fecal matter, and ensuring adequate and hygienic storage conditions are necessary to reduce exposure (Sarrazin et al. 2014). Especial attention should be paid to calf management, since young animals are vulnerable to infection. The practices, which can boost disease resistance, include ensuring sufficient colostrum consumption, availability of clean beddings and less overcrowding. Vaccination has become one of the useful tools in the control of bovine salmonellosis (De la Cruz et al. 2017). Both live and inactivated vaccines are available and have held promise of reducing bacterial shedding clinically and reducing the spread of disease between herds. Vaccines do not offer absolute protection but are an important addition in biosecurity management and management practices. Also, probiotics and competitive exclusion products are emerging as a non-antibiotic alternative to prevent the colonization of pathogenic *Salmonella* within the intestinal tract (Helmy et al. 2023).

Food safety measures are of equal importance from the perspective of the public health (Abu Aisheh et al. 2022). Pasteurization of milk, correct cooking of meat, and good hygiene practices during slaughter and processing are the main ways of decreasing the transmission of Salmonella to humans by cattle. Surveillance systems to monitor infection rates in cattle populations and in human cases also allow outbreaks to be recognised early, and interventions are possible quickly (Meckawy et al. 2022).

3. CONCLUSION

Bovine salmonellosis poses a significant challenge to both animal well-being and human safety worldwide. In calves, the infection elicits high mortality rates, enteritis, septicemia, and even abortion. The disease has contributed to significant economic losses due to treatment costs and declining productivity, as well as the possibility of herd-level epidemics. Transmission is primarily through the fecal-oral route, because of contamination of the feed or water, or the environment, but carrier animals are a persistent source of infection, therefore making eradication difficult. The pathogenesis of *S.* Dublin is related to its capacity to avoid host immune defences and persist long-term in herds. Correct diagnosis is a key element in disease management. Classical culture is common, as are molecular approaches like PCR and serological analysis like ELISA, but all have limitations in one or more of sensitivity, specificity, or strain-level discrimination. This shows that it is necessary to further fine-tune the methods of diagnosis to achieve more accurate early detection and surveillance. *S.* Dublin poses a major public health threat in view of its transmissibility across species and the likelihood of genetic variability. In protecting the health of livestock and humans, there is a need to have integrated control measures such as improved diagnostics and surveillance measures, together with effective herd control. Dedicated research efforts on prevention, early detection and enhanced knowledge of the epidemiology of the pathogen will be essential in containing the spread of *S.* Dublin and risks it poses at the animal-human interface.

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