Comprehensive review of salmonellosis: current status of the disease and future perspectives

Ohoud S. Alhumaidan

Clinical Laboratory Sciences Department, College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia

Abstract

Salmonellosis is a significant public health concern in Saudi Arabia, with various serovars of *Salmonella* causing outbreaks and infections. The disease's clinical presentation includes common symptoms such as diarrhea, fever, and abdominal cramps, with potential complications in severe cases. Diagnosing salmonellosis in Saudi Arabia involves a combination of traditional laboratory methods and molecular techniques to ensure accurate identification and treatment. Preventive measures and control strategies, including vaccination campaigns, food safety protocols, and public health education, have been implemented to mitigate the spread of salmonellosis. Challenges such as antimicrobial resistance, limited healthcare resources in rural areas, and underreporting of cases persist and impact the effective management of the disease. Recommendations for improving salmonellosis prevention and management include enhancing surveillance, implementing public health education campaigns, strengthening food safety regulations, promoting antimicrobial stewardship, investing in research, improving healthcare infrastructure, and fostering collaboration and coordination between sectors. Implementing these recommendations can help Saudi Arabia effectively address the challenges posed by salmonellosis and reduce the burden of the disease on public health.

Correspondence: Ohoud S. Alhumaidan, Clinical Laboratory Sciences Department, College of Applied Medical Sciences, King Saud University, Riyadh, 12372, Saudi Arabia.
E-mail: oalhumaidan@ksu.edu.sa

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Introduction

Salmonella is a facultatively anaerobic, flagellated Gram-negative bacillus with more than 1800 identified serovars distinguished by their O, H, and Vi antigens (Giannella, 1996). Salmonellosis presents a spectrum of conditions, including potentially fatal enteric fevers, gastroenteritis, diarrhea, and fever (Giannella, 1996).

Salmonellosis is a global annual health concern, affecting an estimated 1.3 billion individuals (Dróżdż *et al*., 2021). *Salmonella enterica*, which causes typhoid fever and gastroenteritis, is the most pathogenic *Salmonella* species (Teklemariam *et al*., 2023). Studies have shown that 11.4% of animal-derived food items contained *Salmonella* isolates, with 5.7% found in minced meat, 1.4% in kofta, 1.4% in luncheons, and 2.8% in burgers (Crump *et al*., 2015; Bonardi, 2017; El-Demerdash *et al*., 2021). The incidence of *Salmonella* sp. in plant-based foods was found to be 4.08% in North America, 30.82% in Europe, and 4.08% in Africa (Berrocal Martínez *et al*., 2023). An assessment of the prevalence and diversity of *Salmonella enterica* serovars in animal-based commodities identified poultry as the primary source of the *Enteritidis* serovar's dissemination, with *Salmonella* Typhimurium exhibiting cosmopolitanism (Ferrari *et al*., 2019).

Salmonellosis caused by *Salmonella enterica* often presents with symptoms such as diarrhea, fever, stomach cramps, nausea, vomiting, headaches, muscle aches, weakness, and loss of appetite (Wilson and Wilson, 2021; Badasyan and Nushikyan, 2023). The illness is typically self-limiting and mild, with symptoms resolving within an average of 4-7 days (Lenchenko *et al*., 2019). However, complications such as reactive arthritis or secondary infections in other organs can occur, especially in young children, the elderly, or individuals with compromised immune systems (Teresa *et al*., 2015). While the duration of symptoms can vary, they typically persist for about 1 week (Shim *et al*., 2016).

Salmonellosis is a severe global health issue primarily caused by non-typhoidal *Salmonella* strains, leading to many human infections (Salzman *et al*., 2003; Costa *et al*., 2012; Mellou *et al*., 2013; Alghoribi *et al*., 2019). In Saudi Arabia, *Salmonella spp*. has been identified as a prevalent bacterial agent responsible for epidemics of foodborne illnesses, posing a significant risk to public health. The disease is endemic in the country, resulting in considerable morbidity rates and various clinical manifestations, including fever, diarrhea, nausea, abdominal cramping, and vomiting (Iyer *et al*., 2014). Understanding the serotypes and patterns of

antimicrobial resistance exhibited by *Salmonella* strains in Saudi Arabia is essential for ensuring efficacy in disease prevention and management. Recent studies in Riyadh have identified *Salmonella* Enteritidis (*S.* Enteritis) and *S.* Typhimurium as the prevailing serovars associated with human infections, providing insight into the region's specific genotypes responsible for salmonellosis outbreaks. Additionally, examining critical virulence factors such as SPI-1 and SPI-2 contributes to advancing knowledge of the virulence capabilities of these strains and facilitates the formulation of precise control approaches (Alghoribi *et al.*, 2019).

Salmonellosis has significant economic and health implications globally as one of the most frequently reported foodborne illnesses (Staff *et al*., 2012; Murphy and Oshin, 2015; Al□Rifai *et al*., 2019; Gutema *et al*., 2019; Morgado *et al*., 2021; Alslamah and Abalkhail, 2022; Berrocal Martínez *et al*., 2023; Teklemariam *et al.*, 2023). Surveillance and response systems for infectious diseases, including salmonellosis, are essential for disease prevention and control (Sharaheeli *et al*., 2022). The current reported cases of salmonellosis in Saudi Arabia are likely underestimated, and the incidence rate could be considerably higher (Alsayeqh, 2023). Patients are advised to take precautions to prevent the spread of salmonellosis, including rehydration, antibiotic use, practicing food hygiene, and getting sufficient rest (Finstad *et al.*, 2012; Revolledo and Ferreira, 2012; Sauteur *et al*., 2013; Al-Sarraj and Al-Seghayer, 2021). Developing new medications to combat microbial resistance is also essential.

To date, there has been no comprehensive review of the prevalence of salmonellosis in humans in Saudi Arabia. Therefore, this review addresses the lack of sufficient data on the current incidence of salmonellosis in the country. It aims to provide a comprehensive overview of existing research on the prevalence of salmonellosis, analyze epidemiological patterns, identify prevalent serotypes and transmission sources, evaluate the efficacy of preventive measures, identify associated risk factors, highlight knowledge gaps, and suggest recommendations. Additionally, the review seeks to provide insights to inform public health policies and interventions to reduce the burden of salmonellosis in Saudi Arabia.

Epidemiology of salmonellosis

The historical context of salmonellosis

Salmonellosis, a foodborne disease caused by the *Salmonella* bacteria, constitutes a critical global public health concern. *Salmonella* significantly contributes to the prevalence of foodborne illnesses worldwide, with an annual incidence exceeding 94 million cases and resulting in 115,000 fatalities (Djeghout *et al*., 2017). These figures underscore the substantial impact of *Salmonella*, particularly in economically disadvantaged nations.

Salmonellosis has been a significant public health concern in Saudi Arabia, particularly in the Asir region (Malik *et al.*, 1993). A study conducted between 1989 and 1991 analyzed 142 cases and found *Salmonella* infections to be prevalent in this region. Enteric fever and *S.* Enteritidis gastroenteritis were identified as the two most pervasive *Salmonella* infections (Malik *et al*., 1993). Interestingly, the incidence of enteric fever was higher among non-Saudis compared to the indigenous Saudi population, while the prevalence of gastroenteritis was higher among Saudis (Malik *et al*., 1993). In 2020, a study underscored the prevalence of *Salmonella spp*. as the predominant bacterial agent responsible for epidemics of foodborne illnesses across multiple provinces in Saudi Arabia, highlighting the enduring danger posed by *Salmonella* as a pathogen infecting food within the nation (Alsayeqh, 2023). Due to large-scale gatherings, *Salmonella* infections are significantly more prevalent in Saudi Arabia during the Hajj and Umrah seasons (Iyer et al., 2014). A retrospective study at King Khalid University Hospital identified instances of invasive *Salmonella* infection, with a higher prevalence among females than males. This illustrates the persistent prevalence of salmonellosis in Saudi Arabian healthcare settings (Iyer et al., 2014).

Various investigations conducted in Saudi Arabia throughout the 20th century documented varying rates of salmonellosis prevalence. A study on companion reptiles documented a prevalence rate of 29.2%, suggesting a potential health risk to humans (Khan *et al*., 2022). Another investigation approximated a 5-year mean incidence rate of 3.30 per 100,000 individuals (Alsayeqh, 2023), with Saudi patients exhibiting higher rates than non-Saudi patients. A systematic review reported a pooled *Salmonella* prevalence of 6.6% in the Middle East and North Africa region, with Morocco, Tunisia, and Sudan reporting the highest rates of *Salmonella* infection (McDermott *et al*., 2016; Al□Rifai *et al*., 2019; Gutema *et al*., 2019; Jajere, 2019; Morgado *et al*., 2021). Additionally, a study documented a 15% prevalence of *Salmonella* in samples of ready-to-eat fast foods in Saudi Arabia, highlighting the potential for contamination in these items (Alharbi *et al*., 2019). In conclusion, the study found that two distinct sample groups for locally chilled poultry had 76.76% and 67.0%, prevalence rates respectively (Badahdah and Aldagal, 2018). According to these studies, the prevalence rates of salmonellosis in various populations and dietary sources in Saudi Arabia during the 20th century were inconsistent.

Microbiology of Salmonella

Salmonella enterica ssp. enterica I, *S.* Enteritidis, *S.* Typhimurium, and *S.* Heidelberg are *Salmonella* serovars discovered in Saudi Arabia. These serovars have been identified in a multitude of sources (Alghoribi *et al.*, 2019), including chicken carcasses (Alharbi *et al*., 2019), human clinical isolates (Khan *et al.*, 2022), and ready-to-eat fast foods. *S.* Typhimurium and *S.* Enteritidis were the most prevalent serovars identified in clinical isolates from humans (Alarjani *et al.*, 2021). *S.* Typhimurium was the most pervasive in ready-to-eat fast foods (Al Kraiem *et al*., 2019). *S.* Bredeney, a serovar resistant to third-generation cephalosporins, was also identified in Saudi Arabia. These results highlight the existence of diverse *Salmonella* serovars in Saudi Arabia originating from various sources, highlighting the critical need for implementing surveillance and control protocols to prevent foodborne illnesses.

Salmonella poses a significant public health concern in Saudi Arabia. Studies reveal antibiotic-resistant strains in domestic reptiles (29.2%) and *S.* Typhimurium in poultry carcasses, highlighting potential contamination risks (Alarjani *et al*., 2021; Khan *et al*., 2022). *Escherichia coli*, *Salmonella*, and *Shigella* are frequent causes of foodborne illness, further complicated by growing resistance to treatment antibiotics (Al-Sarraj and Al-Seghayer, 2021). The average incidence rate of salmonellosis between 2013-2017 was 3.30 per 100,000 individuals, with higher rates among Saudi nationals and males (Alsayeqh, 2020). While treated sewage effluent samples often lacked detectable *Salmonella* (98.7%) (Al-Wohaib *et al*., 2022), further investigation is needed regarding water sources. To combat *Salmonella*, it is necessary to implement multifaceted approaches, such as enhanced public health surveillance and education, reduction of antimicrobial resistance, and improvement of food safety practices.

It has been determined that the existing interventions and control measures implemented in Saudi Arabia to prevent salmonellosis are inadequate in accurately estimating the disease's incidence. Salmonellosis cases formally recorded in Saudi Arabia are probably underreported by 37.6 to 345.36, suggesting a substantial deficiency in surveillance and reporting infrastructure (Alslamah and Abalkhail, 2022). *Salmonella* and other members of the *Enterobacteriaceae* family are the leading causes of food poisoning in Saudi Arabia, and resistance has rendered ineffectual the medications used to treat infections caused by these bacteria (Alsayeqh, 2020). Additionally, the research emphasizes the necessity for novel pharmaceuticals to address the issue of microbial resistance (Al-Sarraj and Al-Seghayer, 2021). The oversight and prevention of salmonellosis are additionally complicated in Saudi Arabia. This country is highly dependent on food imports due to the difficulties associated with assuring food safety and adherence to Halal standards (Alrobaish *et al*., 2021). In Saudi Arabia, a comprehensive requirement exists for enhanced control measures, improved surveillance systems, and more accurate disease incidence estimations to effectively mitigate the spread of salmonellosis (Gupta *et al.*, 2018).

Challenges in salmonellosis: diagnosis, treatment, and control

Diagnosing salmonellosis presents challenges due to the need for effective and sensitive techniques to identify viable *Salmonella*, especially when in a viable but non-culturable state. Traditional cultural methods may not detect this state (Zhuang *et al*., 2023). Additionally, the identification of specific groups of *S.* Enteritidis, such as the Global Epidemic, Central/East African, and West African groups, relies on the availability of whole-genome sequencing technology, which can hinder their monitoring and the ability to respond effectively to public health issues (Gallichan *et al*., 2022). Furthermore, identifying genomic clusters worth investigating among *S.* Enteritidis strains can be challenging due to their highly similar character. This requires the use of sophisticated laboratory techniques such as core genome multilocus sequence typing, whole genome multilocus sequence typing, and high-quality single nucleotide polymorphism analysis to break down and improve large clusters to obtain useful information (Ndako *et al.*, 2023). These challenges underscore the importance of developing prompt, precise, and economical diagnostic methods to enhance the diagnosis, monitoring, and response to *Salmonella* outbreaks.

The treatment of salmonellosis faces several challenges, including growing antimicrobial resistance and limited treatment options due to resistance to commonly used antibiotics such as ceftriaxone and ciprofloxacin (Crump *et al*., 2023). The emergence of invasive disease states, leading to high rates of illness and death, further complicates treatment (Al kraiem *et al*., 2018). Additionally, patients with complex medical conditions, especially those at high risk, may experience complications such as extraintestinal infection, mycotic aneurysms, and deep vein thrombosis (Suppamutharwyam and Radhakrishnan, 2022). The mortality rate of nontyphoidal *Salmonella* invasive illness is approximately 15%, underscoring the importance of early identification and treatment to prevent adverse outcomes (Hamilton *et al*., 2012). Furthermore, the increasing antimicrobial resistance, including resistance to third-generation cephalosporins, poses a significant risk to patient health and population well-being (Boichenko *et al*., 2017).

Clinical presentation and diagnosis of salmonellosis

The clinical symptoms of salmonellosis most commonly reported by patients in Saudi Arabia consist of headache, fever, diarrhea, vomiting, and abdominal cramps (Alsubaie and Alrabiaah, 2020). In addition to these, convulsions, hydrocephalus, ventriculitis, and cerebral venous sinus thrombosis have also been documented as additional symptoms (Al-Sarraj and Al-Seghayer, 2021). Although the manifestation of salmonellosis may differ, affected individuals frequently exhibit these symptoms. According to a review of *Salmonella* as a foodborne pathogen, salmonellosis is a significant cause of morbidity and mortality in Saudi Arabia, with clinical manifestations including diarrhea, nausea, abdominal cramping, vomiting, and fever (Iyer *et al*., 2014).

Salmonellosis is diagnosed in Saudi Arabia through a combination of molecular techniques and laboratory tests to ensure accurate identification of the infection. Employing these techniques is critical for verifying *Salmonella* infection and directing suitable treatment. Recent research has provided insights into the diagnostic methodologies used within the nation (Alharbi *et al*., 2021). Laboratory investigations are indispensable for diagnosing salmonellosis in Saudi Arabia. The procedures involve cultivating specimens from diverse sources such as peritoneal fluid, blood, cerebrospinal fluid, stool, urine, biopsied tissue, and mucus. *Salmonella* isolates are commonly identified using automated systems such as Microscan and Vitek GNI. According to the Kauffmann-White classification system, *Salmonella antisera* is used in serotyping (Alharbi *et al*., 2021). These conventional laboratory techniques are essential for confirming the presence of *Salmonella* in clinical samples.

Salmonella infections are increasingly diagnosed using molecular techniques and polymerase chain reaction (PCR) assays are employed to identify *Salmonella* strains in clinical samples from Saudi Arabia (Ohud, 2012). With its high sensitivity and specificity, PCR can identify *Salmonella* by targeting specific genes, such as *invA*. Further investigation has linked the detection of *S. Typhimurium* to additional virulence factors, including the *hipO* gene (Alarjani *et al*., 2021). Recent studies in Saudi Arabia have stressed the importance of these diagnostic techniques in combating salmonellosis (Elbehiry *et al*., 2023). Integrating molecular techniques with conventional laboratory tests significantly improves the diagnostic process, enabling healthcare practitioners to detect and manage cases of salmonellosis on time.

The laboratory methodologies presently employed for diagnosing salmonellosis in Saudi Arabia exhibit certain constraints and prospects for enhancement. According to a study (Abu-Amero, 2002), the emergence of fluoroquinolone-resistant *Salmonella* strains in Saudi hospitals indicates the need for improved diagnostic techniques. Abu-Amero's additional research drew attention to the absence of a national governing body for medical laboratory accreditation in Saudi Arabia, consequently leading to a restricted quantity of accredited laboratories (Khateb and Alkhaibari, 2023). Furthermore, a study conducted by Alsayeqh found that the incidence rates of salmonellosis reported in Saudi Arabia are probably underestimated, indicating the necessity for surveillance systems with greater precision (Alsayeqh, 2020). The results of this study suggest that the existing laboratory methodologies employed to diagnose salmonellosis in Saudi Arabia could be enhanced. This could be achieved by adopting more sophisticated diagnostic techniques and forming a national accrediting organization for medical laboratories. Furthermore, multi-locus sequence typing and pulsed-field gel electrophoresis are employed to conduct addition-

al characterization of *Salmonella* isolates (Al Kraiem *et al*., 2019). For the detection of specific genes, such as 16S rRNA and *hipO* genes utilized in identifying *Campylobacter jejuni* and *S.* Typhimurium (Alarjani *et al.*, 2021), isolates mediated by plasmids and contain quinolone resistance to fluoroquinolones and β-lactams (Aljindan *et al*., 2018). Furthermore, a multiplex PCR technique was developed to identify *Salmonella spp*., *Listeria monocytogenes*, and *E. coli* O157:H7 in cheese samples (Tork *et al.*, 2017). These molecular techniques make rapid and effective methods for diagnosing and characterizing salmonellosis in Saudi Arabia possible.

Risk factors associated with salmonellosis

Salmonellosis within the Saudi Arabian population is susceptible to a multitude of risk factors related to healthcare accessibility, hygiene practices, and dietary behaviors. Dietary practices, including improper food preparation and storage, contribute substantially to *Salmonella* outbreaks (Teklemariam *et al*., 2023). In Saudi Arabia, direct contact with uncooked ingredients, specifically chicken flesh, is identified as the primary vector of the illness (Teklemariam *et al*., 2023). Salmonellosis and other contaminated illnesses are associated with adherence to hygiene practices, which includes preventing cross-contamination among customers and chefs (Alsayeqh, 2020). Furthermore, cultural and environmental factors contribute to the prevalence of salmonellosis in Saudi Arabia (Al Kraiem *et al*., 2019), indicating that environmental factors also contribute to its transmission.

Salmonellosis has been effectively prevented in Saudi Arabia by applying current vaccination strategies. The average incidence rate of salmonellosis over 5 years was 3.30 per 100,000 individuals (Alqahtani *et al*., 2021). According to the study, the incidence rate was higher among Saudi patients than non-Saudi patients (Alsayeqh, 2020). This indicates that the vaccination campaigns executed in Saudi Arabia have effectively mitigated the prevalence of Salmonellosis. Nevertheless, the research also emphasized the possibility that the documented incidence rates in Saudi Arabia are grossly underestimated and suggested employing multipliers to compute a more precise disease incidence (Alrowaili *et al*., 2019). Although the disease burden may be somewhat underestimated, the existing vaccination strategies implemented in Saudi Arabia have effectively prevented salmonellosis.

Salmonellosis preventive measures and control strategies

Implementing a Hazard Analysis Critical Control Point (HACCP) system in restaurants and cafeterias to regulate food safety is one of the public health interventions used in Saudi Arabia to stop the spread of salmonellosis (Alslamah and Abalkhail, 2022). As part of this system, 88.1% of restaurants use a thermometer to check the temperature of cooked and stored food (Javed and AL□Mohaithef, 2023). The Saudi Ministry of Municipal and Rural Affairs has also implemented policies and guidelines to reduce the spread of infectious illnesses, such as salmonellosis (Ohoud, 2022). Other preventive actions the administration takes include travel bans and temperature monitoring in public areas (Alzahrani, 2022). These actions, along with public health education initiatives like the distribution of COVID-19-related instructional materials, have contributed to slowing the spread of infectious diseases in Saudi Arabia (Alzahrani, 2022).

Salmonellosis control measures in Saudi Arabia include antimicrobial susceptibility testing to identify strains resistant to antibiotics and surveillance procedures for disease surveillance and reporting (Alsayeqh, 2020; Khan *et al.*, 2022). Additionally, selective enrichment and plating procedures are used to find *Salmonella* in companion reptiles—which could be potential sources of transmission (Al Kraiem *et al*., 2019). Regarding food safety protocols, standard biochemical and microbiological assays are used to isolate and identify *Salmonella* in fresh leafy greens (Haramain *et al*., 2021). These assays are combined with antimicrobial susceptibility evaluations to determine the resistance profiles strains found (Haramain *et al*., 2021). Efforts are also made to identify genes linked to resistance to fluoroquinolones and β-lactams in *Salmonella* organisms isolated from healthcare institutions using PCR (Aljindan *et al*., 2018).

Studies suggest that reported rates of salmonellosis in Saudi Arabia might be underestimated (Alsayeqh, 2020; Alharbi *et al*., 2021). Existing methods for controlling salmonellosis in the country include food safety measures, with ongoing efforts to ensure improvement (Iyer *et al.*, 2014; Alsayeqh, 2020). Public education programs are aimed at raising awareness about food hygiene among food handlers and the general public (Iyer *et al.*, 2014; Alsayeqh, 2020). Surveillance conducted by the Ministry of Health monitors and reports salmonellosis cases (Alharbi *et al.*, 2021). There is also a suggestion for establishing a national public health laboratory to improve *Salmonella* strain detection (Alsayeqh, 2020). The effectiveness of current methods for controlling salmonellosis in Saudi Arabia varies across different strategies. Safety measures can significantly reduce transmission if consistently implemented throughout the food chain (Alsayeqh, 2020). Strengthening the enforcement of regulations and implementing stricter hygiene protocols could enhance their effectiveness. Public education on proper food handling can improve consumer behavior, but its impact may be limited without addressing contamination sources (Iyer et al., 2014; Alsayeqh, 2020). Targeted campaigns for high-risk groups may be more effective. Surveillance allows tracking of disease trends but is hindered by underreporting (Alharbi *et al*., 2021). Improving healthcare worker awareness, diagnostic capabilities, and patient reporting could enhance surveillance. Additionally, establishing a national public health lab could improve strain detection (Alsayeqh, 2020). Vaccination strategies show promise, but more research is needed for long-term effectiveness (Alsayeqh, 2020). Further investment in research to understand prevalent strains and contamination sources is also crucial. By implementing these improvements alongside existing methods, Saudi Arabia can potentially achieve a more comprehensive and effective approach to controlling salmonellosis.

Outbreaks and surveillance of salmonellosis

Pinpointing specific recent outbreaks of salmonellosis in Saudi Arabia is challenging due to limited available data, including underreporting of cases and limited access to real-time outbreak data (Alsayeqh, 2020; Alharbi *et al*., 2021;). However, past outbreaks, such as the 1998 incident linked to contaminated mayonnaise in Abha, provide insight into the response methods used in Saudi Arabia (al-Ahmadi *et al*., 1998). Many steps have been taken to control and stop the spread of *Salmonella* infections in response to these outbreaks. These include inquiries into the origins of epidemics, evaluations of their scope, and suggestions for averting the

recurrence of similar situations in the future (Aljoudi *et al.*, 2010). Additionally, initiatives have been undertaken to promote clean food and water habits, the prudent use of antibiotics, and ongoing assessments of antibiotic susceptibility to prevent infections, particularly among immunocompromised individuals (Alharbi *et al*., 2021; Rahman *et al.*, 2022; Muteeb *et al*., 2023).

Treatment and management of salmonellosis

Antibiotics are generally successful in treating *Salmonella* infections in Saudi Arabia (Al Shareef *et al*., 2022). An investigation found that *Salmonella* isolates from the country were predominantly Serovar Bredeney and resistant to a limited range of antibiotics (Ali *et al*., 2021). However, one Bredeney isolate was resistant to third-generation cephalosporins while remaining sensitive to other drugs tested (Khan *et al*., 2022). This suggests that antibiotic treatment is generally effective against *Salmonella* infections in Saudi Arabia, though resistance to some drugs may exist. It should be noted that this information is based on a single study, and further research is needed to properly evaluate the efficacy of antibiotics compared to other treatment options for salmonellosis in Saudi Arabia. Healthcare professionals in Saudi Arabia face several challenges in diagnosing and treating *Salmonella* infections. These include antimicrobial resistance, with *Salmonella* strains showing resistance to antibiotics like ceftriaxone, which significantly burdens healthcare systems (Al kraiem *et al.*, 2018). The prevalence of zoonotic *Salmonella* infections in animals, particularly in poultry farms, increases the risk for workers and veterinarians, highlighting the need for effective preventive measures (Al-Harbi *et al*., 2023). Veterinarians also encounter occupational health risks due to zoonotic diseases like salmonellosis, underscoring the importance of proper personal protective equipment usage and safety education (Al-Harbi *et al*., 2023). Diagnostic challenges arise from the wide diversity among *Salmonella* isolates and the presence of non-typed isolates, making accurate diagnosis and treatment decisions more complex (Teklemariam *et al*., 2023). Surveillance data limitations, such as underreporting and lack of representativeness, further compromise the effectiveness of monitoring and managing *Salmonella* infections in Saudi Arabia (Alhumaid *et al*., 2023). These challenges underscore the complexity healthcare professionals face in addressing *Salmonella* infections in the country. The lack of resources and manpower, the necessity for high-quality data, and the establishment of rules and norms pose unique challenges for medical practitioners in Saudi Arabia when diagnosing and treating *Salmonella* infections (Gurajala, 2023; Saeed *et al*., 2023). In rural and border areas, *Salmonella* infections can be challenging to diagnose and treat promptly due to a lack of technological resources and limited access to healthcare (Alslamah and Abalkhail, 2022). Additionally, differences in healthcare accessibility between rural and urban areas may impact the availability of medical resources for detecting and treating *Salmonella* infections (Abalkhail *et al.*, 2022). Resolving these issues is crucial for improving Saudi Arabia's healthcare system and ensuring accurate identification and management of *Salmonella* infections (Al-Anezi *et al*., 2020).

Current treatment strategies and control of salmonellosis

Controlling salmonellosis is challenging due to the emergence of multidrug-resistant strains like *S. Infantis*. These strains pose a significant public health threat as they are more virulent, capable of forming biofilms, and resistant to antibiotics often used as a last resort (Greear *et al*., 2023). In livestock, the interactions between hosts and pathogens are complex. Salmonella can colonize animals without causing symptoms and only occasionally become pathogenic, making it difficult to implement therapies before the animals are harvested (Montoro-Dasi *et al*., 2023). There is a critical need for rapid and accurate detection methods for viable Salmonella, especially in terms of food safety, as traditional culture methods may fail to identify viable but non-culturable variants (Crump *et al*., 2023). Moreover, nontyphoidal Salmonella strains, including *S. Typhimurium* and *S. Enteritidis*, are significant contributors to invasive disease in sub-Saharan Africa. The region is experiencing an increase in antibiotic resistance, which threatens the outcomes of affected patients (Zhuang *et al*., 2023). These challenges underscore the importance of integrated approaches, such as vaccinations and evidence-based therapies, in effectively preventing and controlling salmonellosis.

Controlling salmonellosis involves targeting key components such as antibiotic resistance, biofilm development, and virulence factors (Montoro-Dasi *et al*., 2023). Preventive measures are crucial at both the preharvest and postharvest stages, with a focus on identifying infection sources and implementing control strategies (Allaart *et al.*, 2017). Vaccination is critical for preventing Salmonella infections in chickens, reducing colonization, organ invasion, and environmental contamination, thus decreasing public health risks. Emerging strategies utilize organic acids, natural chemicals, and fungal extracts to combat Salmonella throughout the food chain, aiming to reduce Salmonellosis occurrence in humans and address antimicrobial resistance (Zamora-Sanabria *et al*., 2017). Additionally, developing new vaccine formulations, such as conjugate vaccines, is essential to provide sustained immunity against various Salmonella strains, especially those resistant to multiple drugs like *S. Typhi H58* (Revolledo and Ferreira, 2012).

Currently, addressing treatment resistance in salmonellosis involves employing a variety of methods in combination, focusing on non-inherited resistance mechanisms like biofilms and persister cells. These methods aim to overcome outer membrane barriers, reduce hydrogen sulfide to restrict persister cells, and utilize probiotics or predatory bacteria (Zhou *et al.*, 2023). Additionally, using antibiotics alongside natural components like essential oils has shown potential in combating bacterial resistance. Certain essential oils have demonstrated bioactivity against Salmonella strains and have been effective in reducing antibiotic resistance (Listorti *et al*., 2022). Furthermore, comprehensive surveillance is crucial to understanding the patterns of antimicrobial resistance in Salmonella strains from various sources (Mir *et al*., 2022). This information is essential for developing effective measures to restrict the spread of antimicrobial resistance. Cooperation between the public health, animal health, and animal agriculture sectors is vital for reducing the spread of antibiotic resistance and managing infectious diseases (Lauteri *et al*., 2022).

Conclusions

Salmonellosis presents a significant public health challenge in Saudi Arabia, with various serovars of Salmonella causing outbreaks and infections. The disease's clinical presentation includes common symptoms such as diarrhea, fever, and abdominal cramps, with potential complications in severe cases. Diagnosing

salmonellosis in Saudi Arabia involves a combination of traditional laboratory methods and molecular techniques to ensure accurate identification and treatment. Preventive measures and control strategies, including vaccination campaigns, food safety protocols, and public health education, have been implemented to mitigate the spread of salmonellosis. Challenges such as antimicrobial resistance, limited healthcare resources in rural areas, and underreporting of cases persist and impact the effective management of the disease. Efforts to enhance surveillance, improve diagnostic capabilities, and strengthen preventive measures are essential for reducing the burden of salmonellosis in Saudi Arabia. Continued research and collaboration between healthcare sectors are crucial for developing more effective strategies to control and manage salmonellosis outbreaks in the country.

Recommendation and future direction

To enhance the prevention, diagnosis, and management of salmonellosis in Saudi Arabia, several key recommendations and future directions can be pursued. Firstly, implementing an integrated surveillance system is crucial for accurately monitoring and reporting salmonellosis cases, coupled with efforts to improve reporting mechanisms and enhance laboratory diagnostic capabilities. One health approach in tracking, monitoring, and reducing antibiotic abuse and misuse in animal fields rather than public health education campaigns should be launched to raise awareness about food safety practices, proper hygiene, and the risks associated with salmonellosis among the general public and high-risk groups. Strengthening food safety regulations and implementing HACCP systems in food establishments can help prevent contamination and outbreaks. Promoting antimicrobial stewardship to prevent the development and spread of antibiotic-resistant strains of Salmonella is also essential, including monitoring antimicrobial resistance patterns and promoting appropriate antibiotic use. Research should be prioritized to understand the prevalence, transmission routes, and genetic characteristics of Salmonella strains in Saudi Arabia, leading to the development of more effective prevention and treatment strategies such as vaccines and antimicrobial therapies. Improving healthcare infrastructure, especially in rural and border areas, is necessary to ensure timely diagnosis and treatment of salmonellosis cases. Collaboration and coordination between public health agencies, healthcare providers, and the agricultural sector are critical for a comprehensive approach to addressing salmonellosis. Capacity building of healthcare professionals through training and education programs will enhance their skills in diagnosing and managing salmonellosis, ultimately reducing the burden of the disease on public health in Saudi Arabia.

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