The prevalence of *Salmonella* contamination in beef and beef products: a systematic review and meta-analysis

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Abstract. *Salmonella* continues to be a leading global foodborne pathogen, posing significant threats to public health, economic stability, and food safety systems. This systematic review and meta-analysis aimed to determine the global prevalence of *Salmonella* in beef and its products, guided by the PRISMA 2020 framework, to ensure transparency and rigor. Relevant studies were retrieved from scientific databases using targeted keywords, with the inclusion criteria focused on empirical data regarding *Salmonella* prevalence in beef and beef products. Of the 629 initially identified articles, 51 comprising 72 datasets met the inclusion criteria. Data extraction included variables such as sample size, detection method, and prevalence rates, which were synthesized to generate pooled prevalence estimates. The analysis revealed an overall *Salmonella* prevalence of 9.73% (95% CI: 6.66%–13.28%) across 106,666 samples, with a higher prevalence in beef products (13.71%) than in raw beef (9.30%). Regional disparities were observed, with the highest prevalence observed in Asia and the lowest in Europe and South America. This study confirms the need for targeted interventions, improved processing hygiene, robust monitoring systems, and public awareness campaigns to mitigate *Salmonella* contamination risks, ultimately contributing to enhanced food safety standards globally and aligned with the Sustainable Development Goals.

1 Introduction

Foodborne diseases remain a persistent and pressing global public health concern, with the World Health Organization reporting that contaminated food leads to illness in approximately 600 million individuals each year, resulting in an estimated 420,000 deaths. Among the most vulnerable populations are children under the age of five, who bear a disproportionate burden

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of morbidity and mortality associated with foodborne pathogens. This highlights the urgent need for comprehensive strategies aimed at enhancing food safety and preventing contamination across all stages of the food supply chain [1].

One of the most implicated pathogens in foodborne disease outbreaks is *Salmonella*, particularly in beef and its derivative products [2]. Understanding the prevalence of *Salmonella* in such food items is essential to inform risk assessments, guide public health interventions, and shape evidence-based policies. Therefore, this study employed a systematic review and meta-analysis approach to consolidate and analyze existing data on the prevalence of *Salmonella* in beef and beef products using reputable scientific databases [3].

The significance of this research extends beyond academic research. This contributes to the improvement of public health outcomes by providing safer food processing and handling practices. It also advances the field of food safety by identifying key risk factors and developing effective control measures. Moreover, by supporting increased transparency and trust in food systems, this study aids in restoring consumer confidence. Reducing the incidence of foodborne illnesses also alleviates the socioeconomic burden they impose, particularly in low- and middle-income countries. Overall, this study aligns closely with the United Nations' Sustainable Development Goals, particularly those related to health, food security, and sustainable consumption [4].

2 Method

This study adopted a systematic review and meta-analysis approach to investigate the prevalence of *Salmonella* in beef and beef products, guided by the PRISMA 2020 framework, to ensure methodological transparency and rigor. The research began with the formulation of a clear and focused question, followed by the definition of the inclusion and exclusion criteria to determine study eligibility. Studies were included if they reported empirical data on *Salmonella* prevalence in beef or its derived products, whereas non-English articles, studies lacking primary data, or those focusing on unrelated pathogens or food types were excluded.

Relevant studies were systematically retrieved from scientific databases using targeted keywords such as "*Salmonella* prevalence," "occurrence," "beef," and "beef product." The selection process adhered to the PRISMA 2020 flowchart, which details each phase from identification to final inclusion. Data were then extracted based on specific variables, including the sample size, detection method, location, and prevalence rate. Study quality was assessed to ensure validity, and the extracted data were synthesized through statistical analysis to estimate the pooled prevalence using R Studio for the meta-analysis and to identify variability across studies. This structured approach ensured that the review maintained both scientific integrity and relevance throughout the analysis.

3 Result and discussion

The systematic review and meta-analysis conducted under the PRISMA 2020 framework provided a transparent and structured process to determine the global prevalence of *Salmonella* in beef and beef products.

As seen in Figure 1, the word cloud underscores that the most frequent terms "Salmonella," "beef," and "occurrence" highlight the persistent interest in understanding the risks associated with Salmonella contamination in beef production and consumption.

Fig. 1. Word cloud of the themes interest

The trend in publication activity depicted in Figure 2 reveals a sustained increase in studies on *Salmonella* in beef over time.

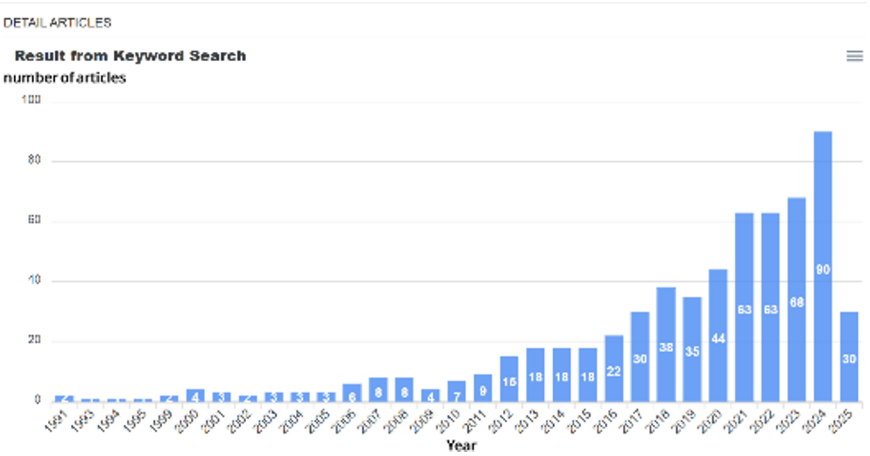

Fig. 2. Graph of the research trend on these themes.

This pattern indicates that *Salmonella* remains a significant food safety concern and that continued scientific attention has been dedicated to addressing this challenge through improved surveillance, detection, and mitigation strategies.

A more granular analysis of the thematic focus is presented in Figure 3. This shows that studies have frequently examined the interconnections between *Salmonella* prevalence and beef product safety. This suggests a holistic scientific interest in not only detecting *Salmonella* but also in investigating the contextual factors that contribute to its presence in beef supply chains, including handling, processing, and consumption patterns.

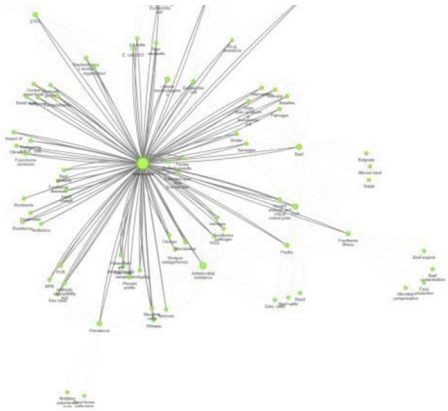

Fig. 3. Keyword analysis of the themes interest.

The systematic nature of the study selection process is illustrated in the PRISMA 2020 flowchart (Figure 4).

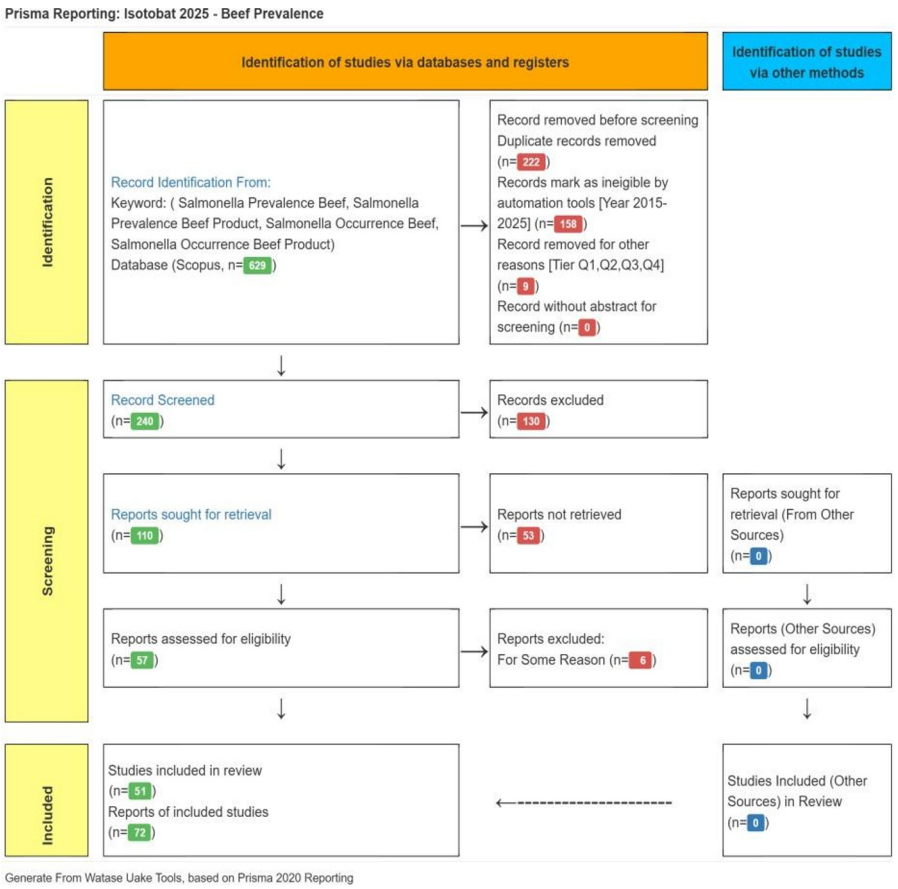

Fig. 4. Flowchart of research stages result (Prisma Reporting).

From an initial pool of 629 articles, 51 studies comprising 72 datasets were rigorously selected to ensure the inclusion of empirical studies that directly measured *Salmonella*

prevalence in beef and beef products. This robust methodological foundation ensured that the prevalence estimates presented in the analysis were both valid and relevant, reflecting actual contamination rates rather than speculative data.

The mapping of studies in Figure 5 demonstrates the wide geographical distribution of the data, highlighting that *Salmonella* in beef is a global concern, spanning multiple continents.

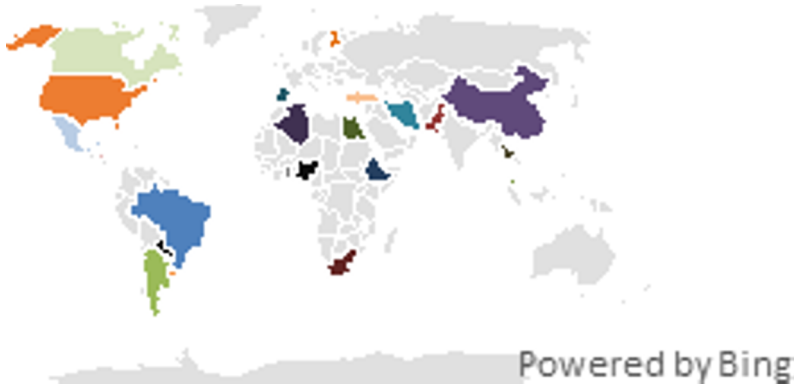

Fig. 5. Global prevalence mapping studies based on inclusion criteria.

This mapping also points to significant regional differences in the intensity of research and reporting, which are influenced by local food safety priorities, regulatory environments, and consumer practices.

The quantitative assessment of publication bias through the funnel plot using the R Studio Freeman-Tukey Double Arcsine transformed portion (Figure 6) indicated symmetry, suggesting a relatively low level of publication bias in the studies included in the meta-analysis. This further reinforces confidence in the pooled prevalence estimates and underscores the rigor of the systematic review and meta-analysis approach.

The numerical results presented in Table 1 reveal that the overall pooled prevalence of *Salmonella* spp. in beef and beef products was 9.73% within a 95% confidence interval of 6.66%–13.28%, based on 2,501 positive cases out of 106,666 samples. This estimate provides a valuable quantitative measure of the global burden of *Salmonella* in beef-related food supply chains [5]. The large sample size across different studies enhances the reliability and statistical power of this pooled estimate, reflecting the comprehensive scope of the systematic review and meta-analysis.

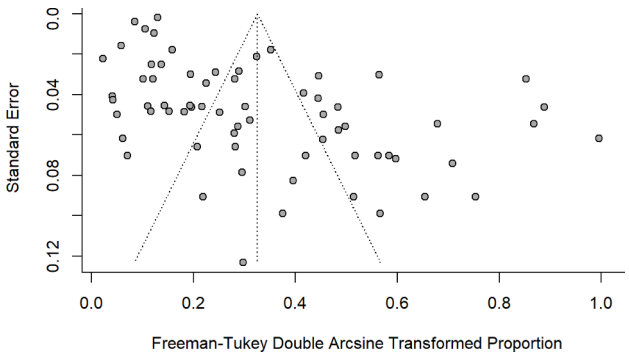

Fig. 6. Funnel plot – meta-analysis overall result – symmetric (low bias publication).

Raw beef samples exhibited a prevalence of 9.30%, with 2,441 positive samples identified out of the 106,142 tested. This relatively high prevalence highlights the potential risks associated with consuming raw or undercooked beef, particularly in settings where hygienic handling practices are insufficient [6].

Table 1. *Salmonella spp*. prevalence studies result summary.

Beef Type	Bacteria	Proportion 95%-CI; % Prevalence	Number of detected samples (n)	Number of totals samples (n)
Overall	***Salmonella spp.***	0.0973 [0.0666; 0.1328]; 9.73 %	2,501	106,666
Raw Beef	***Salmonella spp.***	0.0930 [0.0612; 0.1302]; 9.30 %	2,441	106,142
Beef Products	***Salmonella spp.***	0.1371 [0.0292; 0.2992]; 13.71 %	60	524
Asia		0.1232 [0.0604; 0.2030]; 12.32%	395	4,183
Africa		0.1192 [0.0715; 0.1762]; 11.92%	264	2,609
Europe		0.0115 [0.0000; 0.0613]; 1.15%	50	3,910
North America		0.1168 [0.0358; 0.2334]; 11.68%	1,781	95,227
South America		0.0111 [0.0001; 0.0333]; 1.11%	11	737

Raw beef is often exposed to multiple points of potential contamination during slaughter, carcass dressing, and retail display. These findings underscore the need for stringent hygiene measures at all stages of the beef production and distribution chain, as well as consumer education regarding safe handling and cooking practices.

In contrast, beef products, such as sausages, meatballs, and burgers, demonstrated a notably higher prevalence of 13.71%, albeit based on a smaller sample size of 524 samples, with 60 positive cases identified. This elevated prevalence suggests that handling and processing, including mincing, mixing with additives, and post-processing, contribute significantly to the risk of *Salmonella* contamination in beef products. Studies have shown that these additional steps create opportunities for cross-contamination from equipment, workers, and other ingredients, amplifying the risk of microbial contamination compared with raw beef [1].

Regionally, the analysis identified significant disparities in *the prevalence of Salmonella*. Asia reported the highest prevalence at 12.32%, with 395 positive cases out of 4,183 samples. This higher prevalence may reflect differences in production and slaughtering practices, such as more traditional or small-scale abattoirs, where sanitary standards may not be consistently enforced [7]. Furthermore, in many Asian countries, beef is often sold in open-air markets with limited refrigeration and variable hygiene practices, which further increases the risk of contamination.

Africa reported a prevalence of 11.92% based on 264 out of 2, 609 positive cases. This finding aligns with prior research indicating that challenges in cold chain logistics, limited access to water for sanitation, and inadequate regulatory oversight contribute to elevated *Salmonella* risk in the African beef supply chain. Similarly, North America, despite having the largest sample size of 95,227, recorded a prevalence of 11.68%, highlighting that even in highly developed food safety systems, *Salmonella* contamination remains a persistent concern, possibly linked to the large volume and complexity of beef production and distribution networks [5].

Conversely, Europe and South America exhibited substantially lower prevalence rates (1.15% and 1.11 %, respectively). These findings suggest that stricter regulatory frameworks, better cold chain management, and more rigorous hygiene standards in these regions play critical roles in reducing *Salmonella* prevalence in beef- and beef-derived products. For instance, Europe's well-established food safety legislation, such as the European Union's

stringent hygiene regulations, likely contributes to lower contamination rates compared with regions with weaker enforcement [8].

Additionally, observed regional disparities highlight the need for context-specific interventions. In regions with higher prevalence rates, tailored strategies may include enhanced regulatory oversight, targeted training programs for food handlers, and investment in cold-chain infrastructure. In regions with low prevalence, continuous surveillance and periodic reviews of safety protocols are essential to maintain food safety standards.

The integration of comprehensive data synthesis in this review ensures that the findings provide scientifically and globally relevant foundations for future efforts to enhance food safety and reduce the burden of *Salmonella*-related foodborne illnesses. Ultimately, these efforts support broader public health objectives and contribute to Sustainable Development Goals related to health and consumption practices [7].

4 Conclusion

This systematic review and meta-analysis determined that the overall prevalence of *Salmonella spp*. in beef and beef products was 9.73%, with 2,501 positive cases being identified among 106,666 samples. This review identified a higher prevalence in beef products (13.71%) than in raw beef (9.30%), highlighting the impact of processing and handling practices as critical risk factors. The factors influencing *Salmonella* contamination include processing and handling, storage conditions, and contamination with additives and ingredients. This review underscores the need for targeted interventions to address regional disparities in prevalence, strengthening testing and reporting standards, especially in regions with high prevalence.

Future research should expand this work by investigating regional environmental conditions and cultural differences in beef preparation practices, ultimately contributing to enhanced food safety standards globally and aligned with the SDGs.

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