

# Frequency, serotyping, antibiogram, and seasonality of *Salmonella* isolated from red meat markets

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## Abstract

Bacterial pathogenic strains are as adaptable as *Salmonella* strains and cause diverse intestinal and extraintestinal diseases in humans and other mammals worldwide. Red meat and its products are important hosts for many zoonotic diseases. This work was designed to investigate the frequency, serotypes, and antimicrobial resistance profile of isolated *Salmonella* spp. in red meat (cattle, sheep, and goats) sold in Dhamar Governorate, Yemen. A total of 250 red meat samples were collected from the retail seller market

between July and December 2022. All samples were transported immediately to the laboratory, subcultured on selective enrichment agar, and identified by serotyping and antimicrobial susceptibility tests *via* disk diffusion methods. The results indicated 26 positive samples of *Salmonella* out of the 250 samples (10.4%). Notably, isolates belong to ten various serotypes: *S. Typhimurium* 19.2%, *S. Anatum* 15.4%, *S. Newport* 11.5%, *S. Enteritidis* 11.5%, *S. Muenchen* 11.5%, *S. Infantis* 7.7%, *S. Montevideo* 7.7%, *S. Dublin* 7.7%, *S. Senftenberg* 3.9%, and *S. Arizona* 3.9%. The antibiotic resistance profile revealed that 57.5%, 53.9%, and 53.9% of isolates are resistant to erythromycin, tetracycline, and norfloxacin, respectively. This resistance among *Salmonella* spp. suggests a significant threat to health, which will in turn require an active safety measure and response. On the other hand, the seasonal variations “August and July” were found to be associated with an increased frequency of *Salmonella* isolation.

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## Introduction

The *Salmonella* genus is the leading zoonotic infection and one of the most common foodborne diseases (FBDs) all over the world. The first salmonellosis infection was recorded in swine by two researchers, Salmon and Smith, in 1885 (Chlebicz and Śliżewska, 2018; Al-Gamal *et al.*, 2019; AAP, 2024; CDC, 2024). In addition, *Salmonella* spp. is a common occurrence in the enteric canal of birds, animals, and a wide range of other mammals and humans. It is a universal bacterium observed in nature and is capable of surviving for various months in soil and water (Silva *et al.*, 2021). Among only two types, *S. enterica* and *S. bongori*, more than 2600 serotypes of *Salmonella* are prevalent in the environment (Almashhadany and Osman, 2019; Peruzy *et al.*, 2023).

In humans, pathogenic strains can cause certain life-threatening illnesses, most of which are foodborne infections (Mikoleit, 2010; Ammar *et al.*, 2019; Almashhadany *et al.*, 2022a). Nevertheless, the various strains of *Salmonella* are mainly categorized into two types: typhoidal and non-typhoidal (Woldemariam *et al.*, 2005). The first group includes various species of *Salmonella*-producing typhoid fever and paratyphoid fever (*S. Typhi*, *Paratyphi* A, B, and C) (Hugho *et al.*, 2024).

However, unfortunately, these species are carried only by humans, as confirmed by previous studies reported in most countries in the Middle East, Africa, and the European Union (González-Santamarina *et al.*, 2021; Almashhadany *et al.*, 2022a). Furthermore, it is worth noting that the nontyphoidal *Salmonella* type plays a significant role in the transmission of various *Salmonella* strains across individuals, various animal species, humans, and different mammals (Tan *et al.*, 2022). Therefore, nontyphoidal *Salmonellae* are the predominant strains associated with

foodborne illnesses (El-Prince *et al.*, 2019; Serter *et al.*, 2024).

Human salmonellosis is a serious FBD. According to estimates from the World Health Organization (WHO), around 1.3 billion occurrences of salmonellosis species are reported annually (Almashhadany, 2019). According to Smith (2017), the prevalence of foodborne illnesses is estimated to be 80.3 million incidents, accounting for 85.6% of the total. However, it has been estimated that the occurrence of non-typhoidal *Salmonella* leads to approximately 500,000 fatalities per year. The WHO stated an incidence of 94 million cases of non-typhoidal salmonellosis gastroenteritis in 2018, with foodborne cases accounting for around 85% of the total (Mikoleit, 2010). The WHO has also indicated that FBDs have emerged as a significant public health concern, experiencing a notable rise over the past decade in numerous countries across Asia, Africa, and South America (Almashhadany *et al.*, 2022b; DOH, 2024). Several studies have shown that in developing countries, salmonellosis contributes to diarrhea morbidity (Ngogo *et al.*, 2020) and mortality in childhood, as *Salmonella* is accountable for about 20% of childhood illness cases (Shmeleva, 2020). Correspondingly, some *Salmonella* spp. have been host-specific, while others have a more common host range. Nonetheless, the serovars that cause asymptomatic disease in animals may result in human illnesses (Hohmann, 2001; Shmeleva, 2020). Thus, severe individuals for salmonellosis are children (<5 years), the elderly (Van Duijkeren *et al.*, 2002), and immunocompromised individuals (Heikinheimo *et al.*, 2006; Coburn *et al.*, 2007; Balasubramanian *et al.*, 2019). The main causes of *Salmonella* spp. in individuals are various kinds of food, especially meat and its products. It is understood that *Salmonella* can survive for long periods in most domestic freezers (Ballout *et al.*, 2023).

Conventional, meat-borne *Salmonella* pathogens are usually related to the feeding of raw or undercooked meat. Moreover, *Salmonella* spp. also contaminates meat products throughout and after handling, storage, and manufacturing (Almashhadany *et al.*, 2016; El-Bagoury *et al.*, 2019; Garba *et al.*, 2020; CFIA, 2024).

In Yemen, data are deficient on detailed statistics on the occurrence and cases of *Salmonella* contamination caused by foodborne pathogens, as there are no surveillance systems implemented similar to those in other countries. Therefore, this particular study highlighted the existence of *Salmonella* spp. in meat and its products, particularly in street vendors and in huckster outlets, restaurants, and hotels. Consequently, this study aimed to monitor the frequency and antibiogram profiles of *Salmonella* among red meat sold at retail vending in Dhamar Governorate.

## Materials and Methods

### Study design

This study was conducted from July to December 2022. 250 samples were collected as follows: 80 cattle, 95 sheep, and 75 goats from different places in Dhamar City. The aforementioned specimens were obtained in sterilized plastic bags under a controlled environment at the Laboratory of Veterinary Public Health, located within the Faculty of Veterinary Medicine at Tamar University in Dhamar, Yemen, as per prior study (Almashhadany and Osman, 2019).

### Isolation, identification, and characterization of *Salmonella*

*Salmonella* isolated from red meat was used according to information provided by Mikoleit (2010). Initial detection was done on the Gram stain reaction of all suspected *Salmonella* colonies (Taha *et al.*, 2013; Almashhadany and Osman, 2019), and followed by conventional biochemical tests were indicated according to standardized techniques (Mikoleit, 2010; Liu *et al.*, 2018). A series of biochemical assays were conducted on all possible colonies using a triple sugar iron agar slant to examine the triple sugar iron responses, along with other relevant biochemical investigations (Mir *et al.*, 2015; Garba *et al.*, 2019).

### *Salmonella* serotyping test

All the isolates of *Salmonella* that exhibited distinguishing biochemical reactions have been subjected to serotyping by slide agglutination performing a Remel® kit and manufacturer information for *Salmonella* isolation according to guidelines (Remel Europe Ltd. Clipper Boulevard West, Crossways Dartford, Kent, UK).

### Antimicrobial sensitivity testing profile

This study aims to evaluate the susceptibility of isolates to a screen of eight commonly utilized antibiotics employing the Mueller-Hinton agar disc diffusion assessment, as outlined by HiMedia (Mumbai, India). The modified Kirby-Bauer technique and analysis of inhibition zone diameters around antibiotic discs were conducted following the guidelines set out by the Clinical and Laboratory Standards Institute (Sahu *et al.*, 2018). Table 1 presents the antimicrobial agents that were examined, along with their respective concentrations and inhibition zone diameters for the resistant, intermediate, and susceptible strains.

**Table 1.** Concentrations, inhibition zone diameter for resistant, intermediate, and susceptible tested antibiotics.

Antibiotic	Antibiotic concentration	Inhibition zone diameter (mm)		
		Resistant	Intermediate	Susceptible
Colistin	10 µg	≤8	11-9	≥11
Erythromycin	15 µg	≤13	18-14	≥18
Gentamicin	10 µg	≤12	-	≥13
Kanamycin	30 µg	≤13	17-14	≥18
Neomycin	30 µg	≤12	16-13	≥17
Norfloxacin	10 µg	≤10	15-11	≥16
Streptomycin	10 µg	≤11	14-12	≥15
Tetracycline	30 µg	≤14	18-15	≥19

## Statistical analysis

A comprehensive analysis of the data was conducted using version 21 of the SPSS software package (IBM, Armonk, NY, USA). In essence, the normal approximation process has transformed estimates into confidence intervals. The researchers employed the Chi-square test to examine potential differences among groups and the extent of contamination. A statistical significance criterion of  $p < 0.05$  was established.

## Results

### Frequency of *Salmonella* in raw red meat

Out of 250 various red meat samples, the species of *Salmonella* was detected in 26 samples, and the rate of occurrence was 10.4%. Of note, 8.7% (7/80) of samples from cattle meat, 11.6% (11/95) of sheep meat, and 10.7% (8/75) of goat meat contained *Salmonella* (Table 2). Based on statistical inference, it is estimated that contamination was slightly higher in sheep meat compared to cattle and goat meat. There was no significant difference ( $p < 0.05$ ) between types of meat in terms of *Salmonella* prevalence.

### Identified *Salmonella* serotypes

Regarding serotyping, 10 distinct species of *Salmonella* have been identified in various types of red meat. *S. Typhimurium* (19.2%) and *S. Anatum* (15.4%) were the most often identified serotypes, whereas *S. Senftenberg* and *S. Arizona* were the least reported (3.9%) for each serotype. Additional serotypes and their respective proportions are visually depicted in Table 3.

### Antimicrobial sensitivity pattern of the *Salmonella* isolates

All strains isolated ( $n=26$ ) were examined toward eight generally used antibiotics. Complete sensitivity has been found towards colistin and gentamicin, whereas higher resistance phenotypes to erythromycin (57.7%), as well as tetracycline and norfloxacin with a rate of (53.9%), were found. The complete antibiogram profile is shown in Table 4.

### *Salmonella* spp. temporal distribution

The most significant incidence rate was observed in August (16.3%) followed by July (14.0%), while the lowest rate was found in December (5.1%) and November (5.4%). Of note, the summer season was associated with an incremental increase in *Salmonella* incidence (Table 5).

## Discussion

Salmonellosis has a worldwide occurrence and, according to the Food and Agriculture Organization (FAO) and the World Organization for Animal Health (OIE), has been a predominant and important zoonosis since 1950. A few studies have indicated the significance of red meat and meat products in the spread of *Salmonella* to humans (Musawa *et al.*, 2021; Hugbo *et al.*, 2024). It is the main cause of human bacterial intestinal inflammation worldwide. The prevalence levels differed from high to low among red meat, including 14/50 (28%) of beef, 10/40 (25%) of mutton, and 5/30 (16.67%) of meat contact surfaces (Mir *et al.*, 2015).

**Table 2.** Frequency of *Salmonella* among red meat samples.

Red meat	No. samples	+ive samples, n (%)	-ive samples, n (%)
Cattle meat	80	7 (8.7)	73 (91.3)
Sheep meat	95	11 (11.6)	84 (88.4)
Goat meats	75	8 (10.7)	67 (89.3)
Total	250	26 (10.4)	224 (89.6)

+ive samples, number and percentages of *Salmonella* isolates; -ive samples, *Salmonella* not isolated.

**Table 3.** Serotypes of 26 isolated *Salmonellae* from red meat.

Serotypes	Strains	%
<i>S. Typhimurium</i>	5	19.2
<i>S. Anatum</i>	4	15.4
<i>S. Newport</i>	3	11.5
<i>S. Enteritidis</i>	3	11.5
<i>S. Muenchen</i>	3	11.5
<i>S. Infantis</i>	2	7.7
<i>S. Montevideo</i>	2	7.7
<i>S. Dublin</i>	2	7.7
<i>S. Senftenberg</i>	1	3.9
<i>S. Arizona</i>	1	3.9

**Table 4.** Antimicrobial of isolates to a panel of eight antibiotics.

Antimicrobial agents	No. examined	Sensitive, n (%)	Intermediate, n (%)	Resistant, n (%)
Colistin	26	26 (100)	0 (0)	0 (0)
Erythromycin	26	9 (34.6)	2 (7.7)	15 (57.7)
Gentamicin	26	26 (100.0)	0 (0)	0 (0)
Kanamycin	26	17 (65.4)	2 (7.7)	7 (26.9)
Neomycin	26	11 (42.3)	2 (7.7)	13 (50.0)
Norfloxacin	26	9 (34.6)	3 (11.5)	14 (53.9)
Streptomycin	26	14 (53.8)	2 (7.7)	10 (38.5)
Tetracycline	26	11 (42.3)	1 (3.8)	14 (53.9)

In the current study, the frequency of *Salmonella* in beef, mutton, and chevon meat (goat meat) samples was 26/250 (10.4%) (Table 2). These results are in agreement with those of Taha *et al.* (2013) who carried out a study in Sana'a city from April 2009 to April 2010, which showed that the isolation percentage of *Salmonella* in red meat examples was 14.7%. However, the general spread followed the study executed in China by Yang *et al.* (2020), who illustrated that the beef, mutton, and dumplings showed an average level of contamination with a percentage of 16.1% (n=161) and 10.9% (n=92), respectively.

Recently, a study conducted in Yemen by Al-Khadher (2015) reported *Salmonella* spp. in native beef, imported beef, camel meat, minced meats, poultry meat, fish meat, table eggs, and raw milk, which had contamination percentages with *Salmonella* of 0.11%, 0.14%, 0.05%, 0.11%, 0.05%, 0.16%, 0.19%, 0.14%, and 0.05%, respectively. These studies confirm that *Salmonella* spp. is a frequent contaminant of red meat, including meat products, which could pose an increased risk of infection to humans. The results of the current study also point to poor hygienic practices in the preparation and processing of the carcasses, which serve as a source of contamination.

Nevertheless, the pooled estimates of *Salmonella*-contaminated goat carcasses, beef carcasses, minced beef, and milk were 3.86%, 4.53%, 8.34%, and 10.76%, respectively in Ethiopia (Tadesse and Gebremedhin, 2015).

Also, this study showed lower results than those found in Riyadh, Saudi Arabia, where the prevalence of *Salmonella* was 11.2%, 13.5%, 23.2%, and 18.8% in feces and 80.2%, 51.2%, 67.6%, and 60.2% on hides of cattle, goats, camels, and sheep, respectively (Bosilevac *et al.*, 2015).

Conversely, in Addis Ababa, Ethiopia, out of 384 samples, a total of 4 (1.04%) *Salmonella* spp. were isolated, of which 1.5% and 0.5% were from sheep and goats, respectively (Kassaye *et al.*, 2015). Differences in lower prevalence can be attributable to various factors, including variations in geographical location (Almashhadany, 2021), sanitation practices, laboratory detection methodologies, the number of specimens involved in the investigation, and seasonal shifts (Nair *et al.*, 2015). The contamination observed in the current investigation may be attributed to the direct transmission of *Salmonella* within the animals, or it could be a result of unsanitary circumstances in the abattoirs throughout the processing and handling of carcasses, inadequate waste treatment facilities, unchlorinated water supplies, and substandard personal hygiene practices. These factors may contribute to cross-contamination of red meat samples at any point during the slaughtering process (Woldemariam *et al.*, 2005).

In society-based works, FAO and OIE indicated a relation

between the increase in the spread of *Salmonella* spp. in food from animal sources and an increase in human salmonellosis cases (Doyle *et al.*, 2013; El-Bagoury *et al.*, 2019). Thus, reducing ruminant animal contamination would reduce salmonellosis in humans. The sources of contamination exhibit significant variation, primarily encompassing fecal matter derived from livestock and other animal species (Doyle *et al.*, 2013; Almashhadany and Osman, 2019; El-Bagoury *et al.*, 2019). However, these variations have been well-known throughout the world and are impacted by a variety of variables, such as geographic location (Granato *et al.*, 2018), time, the type of food contaminated with *Salmonella*, and the technique of detection (Bell *et al.*, 2016; Galié *et al.*, 2018).

Concerning *Salmonella* strains isolated in the current study (Table 3), *S. Typhimurium* was the most predominant at 5/26 (19.2%), which is consistent with previous reports in Yemen (Al-Khadher, 2015) and Egypt (Reda and Mohamed, 2014). In addition, a recent study in Iraq showed that the isolated *Salmonella* from sheep meat (3.6%) was similar to that from goat (3.3%) (Hanoun and Al-Samrrae, 2019).

The serovar *S. Typhimurium* was found more frequently, as Fatima *et al.* (2023), in Pakistan, confirmed that the predominant *Salmonella* strains were *S. enterica* serovars and *S. Typhimurium* (45.4%). Yang *et al.* (2020) found that the predominant serovars included *S. enterica* serovar Enteritidis (32.7%), *S. enterica* serovar Indiana (14.2%) and *S. enterica* serovar Typhimurium (11.9%).

Hawwas *et al.* (2022), in Egypt, reported that four serotypes (*S. Typhimurium*, *S. Enteritidis*, *S. Dublin*, and *S. Saintpaul*) were shared between sheep, goats, and humans.

Additionally, this may cause antibiotic resistance in *Salmonella* spp. to increase continuously. Besides, observation logs indicated a two-fold increment in resistant phenotypes of *Salmonella* isolates (from 30% to more than 70%) from the early 1990s to the 2000s (Su *et al.*, 2004). The current result concerning the sensitivity testing showed 57.7%, 53.9%, and 53.9% resistance to erythromycin, norfloxacin, and tetracycline, respectively (Table 4). Conversely, the use of antimicrobials in meat and meat products, particularly red meat, can result in antibiotic-resistant strains (Soufi *et al.*, 2012). The antimicrobial susceptibility of *S. Typhimurium* species regained from the food chain and its products has been studied lately (Van Duijkeren *et al.*, 2002; Xu *et al.*, 2020). This is thought to be because it is the most commonly used drug as a growth promoter, according to prior studies (Alfama *et al.*, 2019; Almashhadany, 2019). Changing resistance levels among isolates to the antibiotics used in this study were shown. Nevertheless, *Salmonella* isolates showed susceptibility to colistin, and this phenomenon could potentially be attributed to the limited

**Table 5.** *Salmonella* spp. temporal distribution in raw red meat samples during the period of study.

Month	No. of examined Cattle meat (no. of positive)	No. of examined Sheep meat (no. of positive)	No. of examined goat meat (no. of positive)	Total examined	No. of positive	%
July	16	19	15	50	7	14.0
August	14	16	13	43	7	16.3
September	13	15	12	40	4	10.0
October	13	16	12	41	4	9.8
November	12	14	11	37	2	5.4
December	12	15	12	39	2	5.1
Total	80	95	75	250	26	10.4

application of these two antimicrobials within the domain of veterinary medicine in Yemen (Almashhadany, 2019; Elsayed *et al.*, 2024). However, *Salmonella* strains discovered in raw red meats and chicken meats in the UK and Tunisia have shown complete susceptibility to levofloxacin, ceftriaxone, as reported by Little *et al.* (2008) and Soufi *et al.* (2012). According to Eng *et al.* (2015) and Soufi *et al.* (2012), the presence of antimicrobial-resistant *Salmonella* in meat and its derivatives poses challenges in maintaining food safety and may be associated with human infections.

In this regard, *Salmonella* occurrence had the highest frequency in August (16.3%) and July (14.0%) (Table 5), while the lowest frequencies were found in November (5.1%) and December (5.4%). In terms of time, a few studies have connected warm periods to a high occurrence of *Salmonella* (Alfama *et al.*, 2019).

Based on prior research conducted in the United States, it was observed that the incidence of salmonellosis exhibited a notable rise throughout the summer season (38.6%) and reached its lowest point in winter (14.5%) (Judd *et al.*, 2019). Furthermore, recent research has indicated that *Salmonella* spp. exhibits variability in their typical reservoirs, as well as in terms of environmental factors, seasonal dissemination, and their capacity to induce human infections (Judd *et al.*, 2019, Kadry *et al.*, 2019). However, a study conducted in Mexico revealed that there was a greater occurrence ( $p < 0.05$ ) of this disease in supermarkets throughout the year compared to wet markets (Regalado-Pineda *et al.*, 2020).

Nonetheless, in the study conducted by Al-Khadher (2015) in Yemen, it was confirmed that food of animal origin in Dhamar Governorate is highly contaminated with certain *Salmonella* spp., with these species representing the main source of *Salmonella* infections in patients in the Governorate. Al-Khadher (2015) stated that out of the 35 stool and 45 blood samples examined, 8 (22.8%) and 22 (48.9%), respectively, tested positive for salmonellosis.

## Conclusions

The objective of the present investigation was to assess the occurrence, serovars, antibiotic resistance, and seasonality of *Salmonella* spp. in red meat (namely beef, mutton, and chevon) obtained from specific retail establishments and butcherries located in Dhamar Governorate. In general, there was a notable occurrence (10.4%) of *Salmonella* spp., with the identified serovars being *S. Typhimurium*, *S. Anatum*, *S. Newport*, *S. Enteritidis*, *S. Muenchen*, *S. Infantis*, *S. Montevideo*, *S. Dublin*, *S. Senftenberg*, and *S. Arizona*. This work should be followed by molecular and epidemiological investigations to evaluate the potential risks to consumer health and analyze the prevalence of antibiotic resistance. Nevertheless, it is recommended to conduct a comprehensive four-season study to assess the evolving epidemiology of *Salmonella* in red meat and its derivatives.

## References

- AAP, 2024. Red book online outbreaks: salmonella outbreak linked to charcuterie meats. Available from: <https://publications.aap.org/redbook/resources/28764/Red-Book-Online-Outbreaks-Salmonella-Outbreak>.
- Alfama ERG, Hessel CT, De Oliveira Elias S, Magalhães CRP, Santiago MFT, Anschau M, Tondo EC, 2019. Assessment of temperature distribution of cold and hot meals in food services and the prediction growth of *Salmonella* spp. and *Listeria monocytogenes*. *Food Control* 106:106725.
- Al-Gamal E, Saeed SB, Victor A, Long T, 2019. Prolonged grief disorder and its relationship with perceived social support and depression among university students. *J Psychosoc Nurs Ment Health Serv* 57:44-51.
- Al-Khadher A, 2015. Prevalence of *Salmonella* in human and foods of animal origin with antibiotic resistance patterns of isolated bacteria in Dhamar governorate, Yemen. *Yemeni J Agric Vet Sci* 1.
- Almashhadany DA, 2019. Occurrence and antimicrobial susceptibility of *Salmonella* isolates from grilled chicken meat sold at retail outlets in Erbil City, Kurdistan region, Iraq. *Ital J Food Saf* 8:8233.
- Almashhadany DA 2021. Meat-borne diseases. In: Ranabhat CL. Meat and nutrition. IntechOpen, London.
- Almashhadany DA, Ba-Salamah HA, Shater AR, Al Sanabani AS, Abd Al Galil F, 2016. Prevalence of *Listeria monocytogenes* in red meat in Dhamar Governorate/Yemen. *Int J Med Health Res* 2:73-8.
- Almashhadany DA, Mayas SM, Ali NL, 2022a. Isolation and identification of *Helicobacter pylori* from raw chicken meat in Dhamar Governorate, Yemen. *Ital J Food Saf* 11:10220.
- Almashhadany DA, Osman AA, 2019. Isolation, serotyping, and antibiogram of *Salmonella* isolates from raw milk sold at retail vending in Erbil city, Iraq. *Bulletin UASVM Animal Sci Biotechnol* 76:116-22.
- Almashhadany DA, Zefenkey ZF, Odhah MNA, 2022b. Epidemiological study of human brucellosis among febrile patients in Erbil-Kurdistan region, Iraq. *J Infect Dev Ctries* 16:1185-90.
- Ammar A, Abdeen E, Abo Shama U, Fekry E, Kotb Elmahallawy E, 2019. Molecular characterization of virulence and antibiotic resistance genes among *Salmonella* serovars isolated from broilers in Egypt. *Lett Appl Microbiol* 68:188-95.
- Balasubramanian R, Im J, Lee J-S, Jeon HJ, Mogeni OD, Kim JH, Rakotozandrainy R, Baker S, Marks F, 2019. The global burden and epidemiology of invasive non-typhoidal *Salmonella* infections. *Human Vaccin Immunother* 15:1421-6.
- Ballout R, Toufeili I, Kharroubi SA, Kassem II, 2023. Raw meat consumption and food safety challenges: a survey of knowledge, attitudes, and practices of consumers in Lebanon. *Foods* 13:118.
- Bell RL, Jarvis KG, Ottesen AR, McFarland MA, Brown EW, 2016. Recent and emerging innovations in *Salmonella* detection: a food and environmental perspective. *Microb Biotechnol* 9:279-92.
- Bosilevac JM, Gassem MA, Al Sheddy IA, Almaiman SA, Al-Mohizea IS, Alowaimer A, Koohmaraie M, 2015. Prevalence of *Escherichia coli* O157:H7 and *Salmonella* in camels, cattle, goats, and sheep harvested for meat in Riyadh. *J Food Prot* 78:89-96.
- CDC, 2024. *Salmonella*. Investigation details. Available from: <https://www.cdc.gov/salmonella/charcuterie-meats-01-24/details.html>.
- CFIA, 2024. Food labeling requirements checklist. Available from: <https://inspection.canada.ca/food-labels/labelling/industry/food-labelling-requirements-checklist/eng/1393275252175/1393275314581>.
- Chlebicz A, Śliżewska K, 2018. Campylobacteriosis, salmonellosis, yersiniosis, and listeriosis as zoonotic foodborne diseases: a review. *Int J Environ Res Public Health* 15:863.
- Coburn B, Grassl GA, Finlay B, 2007. *Salmonella*, the host and disease: a brief review. *Immunol Cell Biol* 85:112-8.

- DOH, 2024. 2024 Salmonella multistate outbreak linked to Italian-style charcuterie meats. Available from: <https://doh.wa.gov/you-and-your-family/illness-and-disease-z/foodborne-illness/outbreaks/2024-salmonella-charcuterie-meats>.
- Doyle MP, Loneragan GH, Scott HM, Singer RS, 2013. Antimicrobial resistance: challenges and perspectives. *Compr Rev Food Sci Food Saf* 12:234-48.
- El-Bagoury N, Ahmed SI, Ahmed Abu Ali O, El-Hadad S, Fallatah AM, Mersal G, Ibrahim MM, Wysocka J, Ryl J, Boukherroub R, 2019. The influence of microstructure on the passive layer chemistry and corrosion resistance for some titanium-based alloys. *Materials* 12:1233.
- El-Prince E, Hussein MF, Abd El-Rahman AM, 2019. Incidence of Salmonella species in table eggs and some egg-based products. *JAVR* 9:1-7.
- Elsayed MM, El-Basrey FH, El-Baz AH, Dowidar HA, Shami A, Al-Saeed FA, Alsamghan A, Salem HM, Alhazmi WA, El-Tarabily KA, Khedr HE, 2024. Ecological prevalence, genetic diversity, and multidrug resistance of Salmonella enteritidis recovered from broiler and layer chicken farms. *Poultry Sci* 103:103320.
- Eng SK, Pusparajah P, Ab Mutalib NS, Ser H-L, Chan KG, Lee LH, 2015. Salmonella: a review on pathogenesis, epidemiology, and antibiotic resistance. *Front Life Sci* 8:284-93.
- Fatima A, Saleem M, Nawaz S, Khalid L, Riaz S, Sajid I, 2023. Prevalence and antibiotics resistance status of Salmonella in raw meat consumed in various areas of Lahore, Pakistan. *Scientific Reports* 13:22205.
- Galié S, García-Gutiérrez C, Miguélez EM, Villar CJ, Lombó F, 2018. Biofilms in the food industry: health aspects and control methods. *Front Microbiol* 9:898.
- Garba B, Habibullah S, Saidu B, Suleiman N, 2019. Effect of mastitis on some hematological and biochemical parameters of Red Sokoto goats. *Vet World* 12:572-7.
- Garba B, Salihu M, Saidu B, Rambo U, 2020. Health hazards of abattoir effluents discharged from the Sokoto central abattoir, Nigeria. *Sokoto J Vet Sci* 18:47-52.
- González-Santamarina B, García-Soto S, Hotzel H, Meemken D, Fries R, Tomaso H, 2021. Salmonella Derby: a comparative genomic analysis of strains from Germany. *Front Microbiol* 12:591929.
- Granato D, Putnik P, Kovačević DB, Santos JS, Calado V, Rocha RS, Cruz AGD, Jarvis B, Rodionova OY, Pomerantsev A, 2018. Trends in chemometrics: food authentication, microbiology, and effects of processing. *Compr Rev Food Sci Food Saf* 17:663-77.
- Hanoun AT, Al-Samrrae IaA, 2019. Isolation and identification of Escherichia coli and Salmonella typhimurium from sheep in Baghdad city. *Iraqi J Vet Med* 43:124-9.
- Hawwas HAEH, Aboueisha AKM, Fadel HM, El-Mahallawy HS, 2022. Salmonella serovars in sheep and goats and their probable zoonotic potential to humans in Suez Canal Area, Egypt. *Acta Vet Scand* 64:17.
- Heikinheimo A, Lindström M, Granum PE, Korkeala H, 2006. Humans as a reservoir for enterotoxin gene-carrying Clostridium perfringens type A. *Emerg Infect Dis* 12:1724-9.
- Hohmann EL, 2001. Nontyphoidal salmonellosis. *Clin Infect Dis* 32:263-9.
- Hugho EA, Kumburu HH, Thomas K, Lukambagire AS, Hald T, Mmbaga BT, 2024. High diversity of Salmonella spp. from children with diarrhea, food, and environmental sources in Kilimanjaro-Tanzania: one health approach. *Front Microbiol* 14:1277019.
- Judd M, Hoekstra R, Mahon B, Fields P, Wong K, 2019. Epidemiologic patterns of human Salmonella serotype diversity in the USA, 1996-2016. *Epidemiol Infect* 147:e187.
- Kadry M, Nader SM, Dorgham SM, Kandil MM, 2019. Molecular diversity of the invA gene obtained from human and egg samples. *Vet World* 12:1033-8.
- Kassaye BK, Hassen DJ, Leja KA, Tsegaye B, 2015. Study on prevalence and distribution of Salmonella Isolates from apparently healthy sheep and goats slaughtered at Addis Ababa abattoir enterprise, Ethiopia. *J Veterinar Sci Technol* 6:268.
- Little C, Richardson J, Owen R, De Pinna E, Threlfall E, 2008. Campylobacter and Salmonella in raw red meats in the United Kingdom: prevalence, characterization and antimicrobial resistance pattern, 2003-2005. *Food Microbiol* 25:538-43.
- Liu H, Whitehouse CA, Li B, 2018. Presence and persistence of Salmonella in water: the impact on microbial quality of water and food safety. *Front Public Health* 6:159.
- Mikoleit M, 2010. WHO global foodborne infections network. A WHO network building capacity to detect, control, and prevent foodborne and other enteric infections from farm to table” laboratory protocol: “isolation of Salmonella and Shigella from Faecal specimens”. Enteric diseases laboratory branch, Centers for Disease Control and Prevention. Atlanta, GA.
- Mir IA, Kashyap SK, Maherchandani S, 2015. Isolation, serotype diversity and antibiogram of Salmonella enterica isolated from different species of poultry in India. *Asian Pac J Trop Biomed* 5:561-7.
- Musawa AI, Bashiru G, Al-Rasheed A, Yakubu Y, Jibril AH, Ballah FM, Sidi S, Lawal N, Bala JA, Odhah MN, Muhammad N, Umar M, 2021. Prevalence and antimicrobial susceptibility profiling of salmonella isolated from poultry products sold in sokoto metropolis, Nigeria. *J Anim Health Prod* 9:148-55.
- Nair A, Balasaravanan T, Malik SS, Mohan V, Kumar M, Vergis J, Rawool DB, 2015. Isolation and identification of Salmonella from diarrheagenic infants and young animals, sewage waste, and fresh vegetables. *Vet World* 8:669-73.
- Ngogo FA, Joachim A, Abade AM, Rumisha SF, Mizinduko MM, Majigo MV, 2020. Factors associated with Salmonella infection in patients with gastrointestinal complaints seeking health care at regional hospital in Southern Highland of Tanzania. *BMC Infect Dis* 20:135.
- Peruzu MF, La Tela I, Carullo MR, Ioele S, Proroga YTR, Balestrieri A, Murru N, 2023. Occurrence and distribution of Salmonella serovars associated with human infection isolated from irrigation waters and food-producing animals in southern Italy: eleven-year monitoring (2011-2021). *Ital J Food Saf* 12:11538.
- Reda M, Mohamed S, 2014. Bacteriological studies of Salmonella typhimurium isolated from cow calves and lambs. *Assiut Vet Med J* 60:47-53.
- Regalado-Pineda ID, Rodarte-Medina R, Resendiz-Nava CN, Saenz-Garcia CE, Castañeda-Serrano P, Nava GM, 2020. Three-year longitudinal study: prevalence of Salmonella enterica in chicken meat is higher in supermarkets than in wet markets from Mexico. *Foods* 9:264.
- Sahu C, Jain V, Mishra P, Prasad KN, 2018. Clinical and laboratory standards institute versus European committee for antimicrobial susceptibility testing guidelines for interpretation of carbapenem antimicrobial susceptibility results for Escherichia coli in urinary tract infection (UTI). *J Lab Physicians* 10:289-93.
- Serter B, Önen A, İlhak OI, 2024. Antimicrobial efficacy of post-

- biotics of lactic acid bacteria and their effects on food safety and shelf life of chicken meat. *Ann Animal Sci* 24:277-87.
- Shmeleva E, 2020. The influence of climate change on the spread of human salmonellosis (mini-review). *Acta Agraria Kaposváriensis* 24:89-107.
- Silva JL, Vieira BS, Carvalho FT, Carvalho RC, Figueiredo EE, 2021. Salmonella behavior in meat during cool storage: a systematic review and meta-analysis. *Animals* 12:2902.
- Smith JL, 2017. Infectious dose and an aging population: susceptibility of the aged to foodborne pathogens. In: Gurtler JB, Doyle MP, Kornacki JL, eds. *Foodborne pathogens: virulence factors and host susceptibility*. Springer, Cham, Switzerland, pp 451-68.
- Soufi L, Sáenz Y, De Toro M, Salah Abbassi M, Rojo-Bezares B, Vinué L, Bouchami O, Touati A, Ben Hassen A, Hammami S, 2012. Phenotypic and genotypic characterization of *Salmonella enterica* recovered from poultry meat in Tunisia and identification of new genetic traits. *Vector Borne Zoonotic Dis* 12:10-6.
- Su L-H, Chiu C-H, Chu C, Ou JT, 2004. Antimicrobial resistance in non typhoid *Salmonella* serotypes: a global challenge. *Clin Infect Dis* 39:546-51.
- Tadesse G, Gebremedhin EZ, 2015. Prevalence of *Salmonella* in raw animal products in Ethiopia: a meta-analysis. *BMC Res Notes* 8:163.
- Taha RR, Alghalibi SM, Saeedsaleh MG, 2013. *Salmonella* spp. in patients suffering from enteric fever and food poisoning in Tamar city, Yemen. *East Mediterr Health J* 19:88-93.
- Tan SJ, Nordin S, Esah EM, Mahrer N, 2022. *Salmonella* spp. in chicken: prevalence, antimicrobial resistance, and detection methods. *Microbiol Res* 13:691-705.
- Van Duijkeren E, Wannet W, Heck M, Van Pelt W, Van Oldruitenborgh-Oosterbaan MS, Smit J, Houwers D, 2002. Sero types, phage types, and antibiotic susceptibilities of *Salmonella* strains isolated from horses in the Netherlands from 1993 to 2000. *Vet Microbiol* 86:203-12.
- Woldemariam E, Molla B, Alemayehu D, Muckle A, 2005. Prevalence and distribution of *Salmonella* in apparently healthy slaughtered sheep and goats in Debre Zeit, Ethiopia. *Small Ruminant Res* 58:19-24.
- Xu Z, Wang M, Zhou C, Gu G, Liang J, Hou X, Wang M, Wei P, 2020. Prevalence and antimicrobial resistance of retail-meat-borne *Salmonella* in southern China during the years 2009–2016: the diversity of contamination and the resistance evolution of multidrug-resistant isolates. *Int J Food Microbiol* 333:108790.
- Yang X, Huang J, Zhang Y, Liu S, Chen L, Xiao C, Zeng H, Wei X, Gu Q, Li Y, Wang J, Ding Y, Zhang J, Wu Q, 2020. Prevalence, abundance, serovars and antimicrobial resistance of *Salmonella* isolated from retail raw poultry meat in China. *Sci Total Environ* 713:136385.