



Multidrug-Resistant *Salmonella enterica* subsp. *enterica* Isolated from Animal-Based Foods in Libya

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ABSTRACT

The emergence of *Salmonella enterica* subsp. *enterica* in food represents a significant public health concern worldwide, particularly in developing countries such as Libya. Addressing antimicrobial resistance in *Salmonella enterica* subsp. *enterica* is essential, particularly where food hygiene and antimicrobial regulations are weak. The present study aimed to evaluate the occurrence and antimicrobial susceptibility profile of *Salmonella enterica* subsp. *enterica* isolated from different animal-derived food products collected at retail markets in Libya. In the current study, 18 *Salmonella enterica* subsp. *enterica* isolates were obtained from 751 food samples, including milk, dairy products, meat, and meat products, collected randomly from retail markets in Libya. The isolates were tested for antimicrobial susceptibility, and their antibiotic resistance profiles were evaluated against 33 antibiotics representing 12 different classes. Antimicrobial susceptibility testing demonstrated that all isolates were 100% resistant to penicillin, with high resistance rates to neomycin and rifampicin (94.4%). However, high susceptibility rates were observed for chloramphenicol, nitrofurantoin, sulfamethoxazole/trimethoprim, and norfloxacin (88.9%). The multiple antibiotic resistance (MAR) index varied from 0.1 to 0.6, with the maximum MAR value (0.6) recorded in isolates exhibiting resistance to 21 antibiotics. The current findings underscore the necessity to enhance food safety protocols, as multidrug resistance was prevalent among the isolates, particularly to penicillin, neomycin, and rifampicin. Therefore, the utilization of antimicrobial agents in both veterinary and human settings should be strictly regulated to control the emerging threat of multidrug-resistant strains. Additionally, the present results suggested that fluoroquinolones and cephalosporins remain among the most effective antimicrobial agents and may be considered for the treatment of salmonellosis. The detection of multidrug-resistant *Salmonella enterica* subsp. *enterica* in animal-derived foods in Libya represented a significant public health concern, underscoring the critical need for enhanced surveillance, stricter antimicrobial use regulations, and improved food safety measures.

Keywords: Foodborne pathogen, Meat, Milk, Multidrug resistance, *Salmonella enterica* subsp. *enterica*

INTRODUCTION

Foodborne diseases pose a major global public health challenge, mainly caused by consuming contaminated food, particularly products derived from animal sources. Foodborne illnesses are responsible for an estimated 600 million cases of sickness and approximately 420,000 fatalities annually worldwide (Temesgen et al., 2025). Approximately one-third of people in developed countries are affected annually (Asfaw Geresu et al., 2021). The incidence of foodborne diseases is considerably higher in developing countries due to poor hygiene practices, weak regulatory systems, limited resources, and low awareness of safe food handling practices (Wabeto et al., 2017; Bedassa et al., 2023). Most foodborne pathogens originate from animals and can be transmitted through animal-derived products such as milk, meat, cheese, and yogurt (Ejo et al., 2016; Gebeyehu et al., 2022). Although milk and dairy products are essential to human nutrition, raw milk may contain pathogenic microorganisms introduced by infected animals, handlers, or contaminated farm environments, posing a substantial risk to public health (Bereda et al., 2018; Geletu et al., 2022).

Pathogens originating from animal-derived foods, including *Escherichia coli*, *Staphylococcus aureus*, *Salmonella* species, and *Listeria monocytogenes*, represent one of the most significant threats to human health (Gebeyehu et al., 2022; Sherif et al., 2025). Among these pathogens, *Salmonella* species is one of the most common foodborne bacteria worldwide, causing substantial public health and economic burdens, particularly in developing countries (Carrasco et al., 2012; Asfaw Geresu et al., 2021; Garbaj et al., 2022). Multiple factors contribute to outbreaks of salmonellosis in humans, including the consumption of raw or improperly processed foods, cross-contamination during food preparation, inadequate food storage, poor personal hygiene practices, insufficient refrigeration, inadequate reheating of food, and extended time intervals between food preparation and consumption (Ejo et al., 2016).

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Salmonella comprises two species, *Salmonella bongori* and *Salmonella enterica* (*S. enterica*; Gebeyehu et al., 2022). Among *Salmonella* species, *S. enterica* is the most prevalent and widely distributed, with more than 2,600 identified serotypes. *Salmonella* species are broadly classified into typhoidal and non-typhoidal groups. Globally, *Salmonella enterica* serovars Typhimurium and Enteritidis account for nearly fifty percent of all human infections attributable to non-typhoidal *Salmonella* (Talukder et al., 2023). Most pathogenic and zoonotic *Salmonella* strains belong to *S. enterica* subsp. *enterica*, which causes salmonellosis in both animals and humans (Talukder et al., 2023).

In the past, antibiotics were regarded as highly effective agents for completely eradicating microbial infections. However, microorganisms have demonstrated the ability to survive and even proliferate in the presence of antibiotics, a phenomenon known as antimicrobial resistance (AMR), which has become a significant global concern (WHO, 2023). Currently, AMR in both humans and animals has reached alarming levels globally and was recognized as a major emerging threat to public health and food security (Geletu et al., 2022). Antibiotic-resistant *Salmonella* species originating from animal-derived foods have been increasingly reported, largely due to the misuse and overuse of antibiotics in livestock production (Abunna et al., 2017; Ketema et al., 2018). Antibiotic-resistant *Salmonella* species can be transmitted to humans via the food chain, thereby posing a substantial public health risk (Abunna, 2018). Many *Salmonella* isolates exhibited resistance to commonly used antimicrobial agents, particularly ampicillin, tetracycline, chloramphenicol, and trimethoprim-sulfamethoxazole. Therefore, multidrug-resistant (MDR) non-typhoidal *Salmonella* has become an increasing global concern (Winokur et al., 2000). In contrast, typhoid fever, caused by *Salmonella Typhi*, is typically treated with fluoroquinolones, third-generation cephalosporins, and macrolides (Adel et al., 2021; Asfaw Geresu et al., 2021; Kanat and Terzi Gulel, 2025).

Transmission of antibiotic-resistant pathogens to humans may occur through exposure to antibiotic residues in animal-derived foods. A recent study analyzing a variety of food samples derived from animal sources, human contact, and other environments reported a high prevalence of MDR to more than two antibiotics, particularly fluoroquinolones and third-generation cephalosporins, among *Salmonella* isolates (Asfaw Geresu et al., 2021). Recently, the emergence of antibiotic-resistant foodborne pathogens in the food chain has posed a serious risk of transmission to humans and may lead to higher infection rates. It is important to note that commonly encountered antibiotic-resistant bacteria, such as *Escherichia coli*, *Salmonella*, and *Staphylococcus aureus*, are likely to exert considerable pressure on healthcare systems globally (Naas et al., 2019; Geletu et al., 2022; Temesgen et al., 2025).

Antibiotic misuse is widespread in Libya, where medicines such as ampicillin, amoxicillin, tetracycline, and trimethoprim-sulfamethoxazole are readily available from private pharmacies without a prescription (Ghenghesh et al., 2013). A local study conducted in Tripoli, Libya, reported that 75% of *Salmonella* isolates obtained from children with diarrhea were MDR (Ali et al., 2005), while Rahouma (2011) reported that 63% of the strains were resistant to ciprofloxacin. Therefore, enhancing public awareness of *Salmonella* infections and conducting additional investigations on the prevalence and antimicrobial susceptibility of *S. enterica* in foods are essential. Hence, the present study aimed to determine the prevalence and antimicrobial susceptibility profile of *S. enterica* isolated from selected animal-origin foods in Libya.

MATERIALS AND METHODS

Salmonella isolates

Ethical approval was not required for the present study, as no live animals were involved. The *Salmonella enterica* subsp. *enterica* isolates used in the present study were obtained from previous investigations (Eshamah et al., 2020; Garbaj et al., 2022), in which a total of 751 food samples, including milk, dairy products, meat, and meat products, were collected from retail markets in Libya. In previous studies, *Salmonella* isolates were recovered, identified, and subsequently stored at -80°C for further analysis. The present laboratory-based descriptive study employed a total of 18 *Salmonella enterica* subsp. *enterica* isolates, which were recovered and archived from a previous investigation. Of the 751 food samples examined, 131 consisted of milk and dairy products, including ricotta, massora, and raw cow's milk. The remaining 620 samples comprised meat and meat products, such as minced beef, beef sausage, chicken breast, chicken burger, camel liver, and cattle liver. Animal-origin food samples were randomly collected from retail markets in Tripoli, Sabha, Tobruk, and Regdalin, Libya. During the present experiment, the isolates were revived from -80°C storage by taking a single cryobead from each cryovial and transferring it into 5 mL of peptone water. The cultures were subsequently incubated for 24 hours at 35-37°C before further analysis.

Antimicrobial susceptibility testing

The antimicrobial susceptibility of the *Salmonella* isolates was determined using the Kirby-Bauer disk diffusion method (Antrim BT41, England) on Mueller-Hinton agar (MHA), following the guidelines of the Clinical and

Laboratory Standards Institute (CLSI). Briefly, the procedure involved growing a sterile nutrient broth culture of every isolate to the logarithmic phase and then normalizing the turbidity of the suspension to match a 0.5 McFarland standard. Following this standardization step, the bacterial suspension was spread evenly across the surface of MHA plates using a swabbing technique, then allowed to air-dry for approximately five minutes.

A total of 33 antibiotic disks representing 12 antimicrobial classes (Antrim Technology Park, Antrim BT41, England) were placed on the surface of the inoculated agar plates. The antibiotics tested included amoxicillin (AMX, 30 µg), ampicillin (AP, 30 µg), amoxicillin/clavulanate (AC, 20/10 µg), penicillin (P, 10 µg), methicillin (ME, 5 µg), piperacillin/tazobactam (PTM, 100/10 µg), cloxacillin (OB, 5 µg), ticarcillin/clavulanate (TCL, 75/10 µg), cefepime (CFP, 30 µg), cefoperazone (COZ, 75 µg), cefotaxime (CTX, 30 µg), ceftriaxone (CFT, 30 µg), ceftiofur (CFO, 30 µg), imipenem (IMP, 10 µg), meropenem (MER, 10 µg), ertapenem (ERT, 10 µg), neomycin (NEO, 10 µg), kanamycin (KAN, 30 µg), gentamicin (GEN, 10 µg), tobramycin (TOB, 10 µg), streptomycin (S, 10 µg), tetracycline (TET, 30 µg), doxycycline (DO, 30 µg), oxytetracycline (OT, 30 µg), levofloxacin (LEV, 5 µg), ciprofloxacin (CIP, 5 µg), polymyxin (POM, 300 units), chloramphenicol (CHL, 30 µg), sulfamethoxazole/trimethoprim (COT, 23.75/1.25 µg), aztreonam (AZT, 30 µg), nitrofurantoin (NIT, 300 µg), rifampicin (RIF, 5 µg), and norfloxacin (NOR, 10 µg). The plates were incubated at 37°C for 24 hours, after which the inhibition zone diameters were measured and interpreted according to CLSI guidelines.

Multiple antibiotic resistance index

Multiple antibiotic resistance (MAR) values were determined and interpreted according to the method described by Hinton and Linton (1983) using the following formula.

$$\text{MAR index} = a/b$$

Where a represents the number of antibiotics against which an individual isolate is resistant, and b represents the total number of antibiotics tested. An A MAR index of 0.2 or higher (≥ 0.2) indicated that the isolate originated from a high-risk source where antibiotics were frequently used or misused.

Identification of multi-drug resistance, extensively drug-resistant, and pan-drug-resistant isolates

The isolates were categorized based on their resistance profiles as MDR, which was characterized by resistance to at least one antimicrobial agent across three or more distinct antimicrobial classes, extensively drug-resistant (XDR), defined by resistance to at least one antimicrobial agent in all but two or fewer antimicrobial classes, and pan drug-resistant (PDR), identified by resistance to all tested agents within all antimicrobial classes. The MDR, XDR, and PDR values for each isolate were determined according to the criteria established by Magiorakos et al. (2012) and WHO (2023).

RESULTS

Prevalence

Among the examined food samples, including raw milk, dairy products, meat, and meat products, 18 bacterial isolates were identified as *Salmonella enterica* subsp. *enterica* using conventional microbiological techniques and confirmed by partial 16S rDNA sequencing in the previous studies. Of these 18 isolates, the highest prevalence was observed in raw cow's milk, with 7 isolates (39.1%). Two isolates (11.1% each) were recovered from camel liver, cattle liver, and minced beef. The lowest prevalence of *Salmonella enterica* subsp. *enterica* (5.5%) was observed in chicken burger, beef sausage, chicken breast, massora, and ricotta.

Antimicrobial profiles

The antimicrobial susceptibility profiles of the confirmed *Salmonella enterica* subsp. *enterica* isolates are presented in Table 1. A total of 18 isolates were tested against 33 antimicrobial agents (Figure 1). All isolates exhibited complete resistance (100%) to penicillin. High resistance rates were observed for neomycin and rifampicin (94.4%), whereas resistance to aztreonam and tobramycin was low (5.6%). Among fluoroquinolones, levofloxacin and ciprofloxacin exhibited the lowest resistance rates (16.7%, 3/18), followed by norfloxacin (11.1%, 2/18). Within the cephalosporin class, ceftiofur was the most effective, with a susceptibility rate of 83.3% (15/18), while cefoperazone and cefepime indicated lower susceptibility rates of 61.1% and 38.9%, respectively. None of the isolates were resistant to imipenem, but 38.9% (7/18) exhibited resistance to meropenem. A notable proportion of isolates displayed intermediate resistance, particularly against cloxacillin (100%), polymyxin (83.3%), and kanamycin (66.7%). Overall, the highest susceptibility rates were observed for chloramphenicol, nitrofurantoin, sulfamethoxazole/trimethoprim, and norfloxacin, each demonstrating a susceptibility rate of 88.9%.

Table 1. Antibiotic susceptibility profiles of *Salmonella enterica* subsp. *enterica* from foods of animal origin

Categories	Antibiotics	Susceptible (%)	Intermediate (%)	Resistant (%)	MDR (%)
Carbapenems	Imipenem 10µg	12 (66.7)	6 (33.3)	0 (0)	0
	Meropenem 10 µg	1 (5.6)	10 (55.6)	7 (38.9)	38.9
	Ertapenem 10µg	10 (55.6)	5 (27.8)	3 (16.7)	16.7
Cephalosporins	Cefepime 30µg	7 (38.9)	11 (61.1)	0 (0)	0
	Cefoperazone 75 µg	11 (61.1)	10 (55.6)	3 (16.7)	16.7
	Cefotaxime 30 µg	6 (33.3)	11 (61.1)	1 (5.6)	5.6
	Ceftriaxone 30 µg	6 (33.3)	7 (38.9)	5 (27.8)	27.8
	Cefoxitin 30 µg	15 (83.3)	2 (11.1)	1 (5.6)	5.6
Penicillin	Amoxicillin 30 µg	13 (72.2)	1 (5.6)	4 (22.2)	22.2
	Ampicillin 30 µg	9 (50)	5 (27.8)	4 (22.2)	22.2
	Ticarcillin 75 µg + Clavulanate 10 µg	6 (33.3)	8 (44.4)	4 (22.2)	22.2
	Cloxacillin 5 µg	0 (0)	18 (100)	0 (0)	0
	Methicillin 5 µg	1 (5.6)	2 (11.1)	15 (83.3)	83.3
	Piperacillin 100 µg / Tazobactam 10 µg	1 (5.6)	13 (72.2)	4 (22.2)	22.2
	Amoxicillin clavulanate 20 µg/10 µg	12 (66.7)	1 (5.6)	5 (27.8)	27.8
	Penicillin 10 µg	0 (0)	0 (0)	18 (100)	100
Monobactam	Aztreonam 30 µg	14 (77.8)	3 (16.7)	1 (5.6)	5.6
Aminoglycosides	Neomycin 10 µg	0 (0)	1 (5.6)	17 (94.4)	94.4
	Kanamycin 30 µg	3 (16.7)	12 (66.7)	3 (16.7)	16.7
	Gentamicin 10 µg	13 (72.2)	3 (16.7)	2 (11.1)	11.1
	Tobramycin 10 µg	10 (55.6)	7 (38.9)	1 (5.6)	5.6
	Streptomycin 10 µg	1 (5.6)	9 (50)	7 (38.9)	38.9
		Levofloxacin 5 µg	11 (61.1)	4 (22.2)	3 (16.7)
Fluoroquinolones	Ciprofloxacin 5 µg	10 (55.6)	5 (27.8)	3 (16.7)	16.7
	Norfloxacin 10 µg	16 (88.9)	0 (0)	2 (11.1)	11.1
		Oxytetracycline 30 µg	0 (0)	7 (38.9)	11 (61.1)
Tetracyclines	Tetracycline 30 µg	8 (44.4)	0 (0)	10 (55.6)	55.6
	Doxycycline 30 µg	9 (50)	1 (5.6)	8 (44.4)	44.4
		Sulfamethoxazole 23.75 µg / Trimethoprim 123.25 µg	16 (88.9)	0 (0)	2 (11.1)
Sulfonamides					
Phenicols	Chloramphenicol 30 µg	16 (88.9)	0 (0)	2 (11.1)	11.1
Nitrofurantoin	Nitrofurantoin 300 µg	16 (88.9)	0 (0)	2 (11.1)	11.1
Rifampicin	Rifampicin 5 µg	1 (5.6)	0 (0)	17 (94.4)	94.4
Glycopeptides	Polymyxin 300 units	3 (16.7)	15 (83.3)	0 (0)	0

MDR: Multidrug-resistant

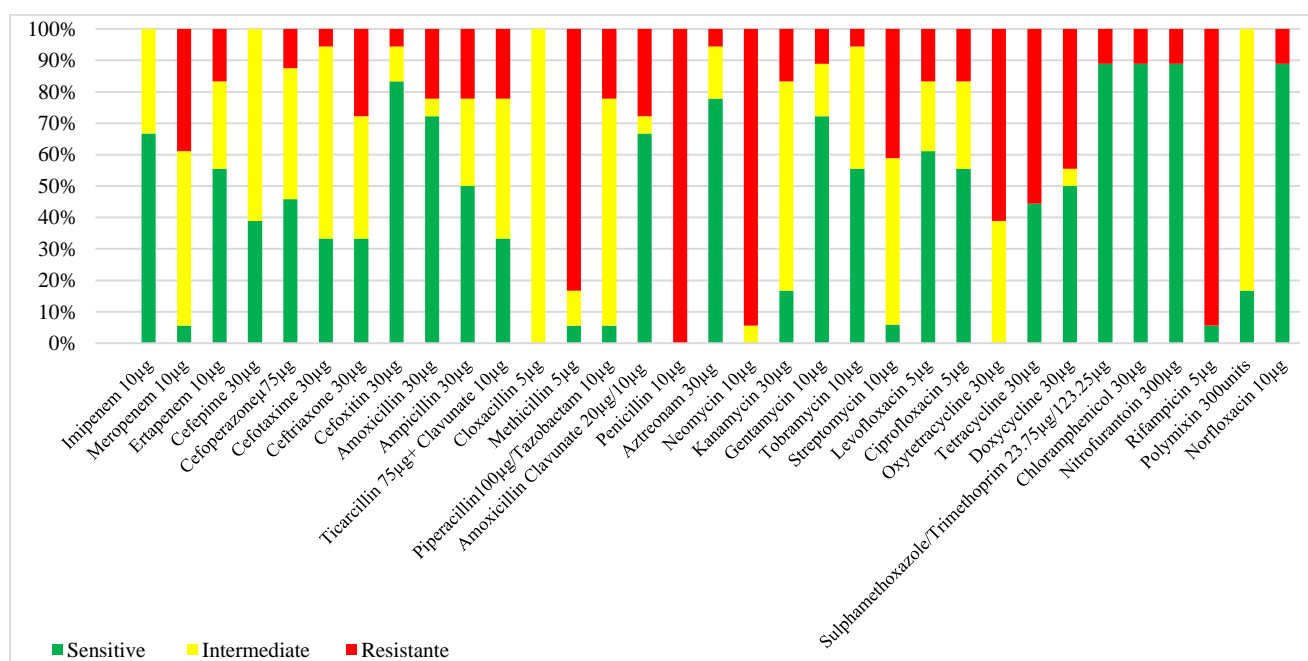


Figure 1. Antimicrobial susceptibility profiles of *Salmonella enterica* subsp. *enterica* isolated from foods of animal origin against 33 antimicrobial agents. All isolates exhibited different degrees of resistance, with the highest resistance observed against penicillin (100%).

Multiple antibiotic-resistant index

In the present study, the MAR index of *Salmonella enterica* subsp. *enterica* isolates ranged from 0.1 to 0.6. The highest MAR values were observed in isolates from chicken breast (S18, 0.6) and chicken burger (S34, 0.5), indicating significant exposure to multiple antibiotics. In contrast, isolates from raw cow's milk samples (S22, S38, S40, and S42) exhibited the lowest MAR indices (0.1; Table 2).

Multi-drug resistant patterns of *Salmonella enterica* subsp. *enterica*

All 18 tested isolates exhibited resistance to three or more antimicrobial classes, indicating MDR. Resistance patterns differed among the isolates, with numbers ranging from 4 to 9 antimicrobial classes (Table 2). The majority of isolates were MDR, reflecting extensive resistance across the tested samples. The highest level of resistance was observed in isolates S18 (from chicken breast) and S43 (from raw cow's milk), each resistant to nine antimicrobial classes. In contrast, isolates S22 and S42, both recovered from raw cow's milk, exhibited resistance to a minimum of four antimicrobial classes. No XDR or PDR isolates were identified in the current study.

Table 2. Antibiotic resistance profiles, multiple antibiotic resistance index, antibiotics class resistance in *Salmonella enterica* subsp. *enterica* isolated from foods of animal origin

Isolates no	Food sample	Resistant antibiotic	MAR index	Antimicrobial classes
S17	Minced beef	10	0.3	5
S18	Chicken breast	21	0.6	9
S19	Beef sausage	13	0.3	7
S20	Camel liver	10	0.3	6
S22	Raw cow's milk	4	0.1	4
S28	Camel liver	11	0.3	6
S29	Cattle liver	9	0.2	5
S30	Cattle liver	10	0.3	7
S34	Chicken burger	17	0.5	7
S38	Raw cow's milk	6	0.1	5
S40	Raw cow's milk	6	0.1	5
S41	Raw cow's milk	12	0.3	7
S42	Raw cow's milk	5	0.1	4
S43	Raw cow's milk	17	0.5	9
S92	Massora	7	0.2	5
S211	Minced beef	12	0.3	7
S307	Raw cow's milk	8	0.2	6
S308	Ricotta	7	0.2	6

MAR: Multiple antibiotic resistance

DISCUSSION

Salmonella enterica subsp. *enterica* is responsible for some of the most severe febrile infections, exhibiting high morbidity and mortality rates in developing countries (Roy et al., 2015). The prevalence of *S. enterica* subsp. *enterica* in foods of animal origin differed across countries (Elbediwi et al., 2021). In the present study, *S. enterica* subsp. *enterica* was detected as a microbial contaminant in milk, different dairy products, meat, and meat products. The highest prevalence was observed in raw cow's milk samples (39.1%). Similarly, Adzitey et al. (2025) reported the highest incidence of *S. enterica* in raw cow's milk at 38.0% in Ghana. In contrast, in Ethiopia, the prevalence of *Salmonella* in fresh cow's milk was reported to be lower, at 9.3% (Asefa et al., 2023). The variation in reported prevalence rates of *Salmonella enterica* in raw cow's milk in the current study, in Ghana (38.0%), and in Ethiopia (9.3%) may be attributed to differences in regional ecological conditions, sample size, animal husbandry practices, and milking hygiene (Adzitey et al., 2020). Consequently, the consumption of contaminated raw milk and its products posed a significant public health hazard in countries such as Libya, where many people consume raw milk without prior heat treatment.

According to the present findings, the incidence of *S. enterica* in ricotta and massora cheese samples was 5.5%. In contrast, Aragão et al. (2019) and Rebić et al. (2022) did not detect *S. enterica* in examined curd cheese samples. In the present study, the prevalence of *S. enterica* in chicken breast meat (5.5%) was lower than that reported by Regalado-Pineda et al. (2020), who reported a prevalence of 18.1% in chicken meat samples. Additionally, Khan et al. (2024) reported a notably higher prevalence of *S. enterica* in poultry (60%) than in other food types, including dairy products (33.3%), beef (30%), vegetables (26.7%), and fruits (20%). Although the prevalence of *S. enterica* in chicken breast

meat was comparatively low, the *Salmonella* isolate number S18 exhibited the highest antimicrobial resistance among all isolates in the present study, highlighting the potential risk posed by even low-prevalence sources.

In Libya, salmonellosis was not officially classified as an outbreak disease, and limited data were available to definitively assess the current state of food safety governance (Abuhlega, 2023). Nevertheless, different studies have investigated the occurrence of *Salmonella* in Libya (Garbaj et al., 2022; Asheg et al., 2023). A study conducted in Zliten, central Libya, reported that *Salmonella* was detected in approximately 13.6% of diarrheal cases among children, often in co-infection with other pathogens, and many of the identified strains exhibited resistance to commonly used antibiotics, including ampicillin, tetracycline, chloramphenicol, and trimethoprim-sulfamethoxazole (Ali et al., 2005). Additionally, a study in Tripoli found *Salmonella* in about 8% of food samples from bakeries, poultry outlets, and camel meat butcheries, with the highest prevalence observed in poultry product shops (Ibrahim et al., 2022).

In the present study, the antimicrobial susceptibility of *S. enterica* subsp. *enterica* isolates were evaluated against 33 antibiotics from 12 classes. All isolates exhibited different degrees of resistance, with the highest resistance observed against penicillin (100%, 18/18). Additionally, methicillin revealed a high resistance rate of 83.3%. The high resistance rates were consistent with those reported by Elshebrawy et al. (2022), who found that the highest resistance rates among *S. enterica* isolates recovered from frozen chicken carcasses in Egypt were to oxacillin (94.7%), penicillin (86.8%), and ampicillin (26.3%). The high resistance rates observed against penicillin in the present study may be attributed to its frequent use as a first-line treatment for bacterial infections in humans and animals, which can drive the development of microbial resistance (Shenoy et al., 2019). The susceptibility of isolates to amoxicillin and ampicillin was relatively high in the present study. The relatively high susceptibility of the isolates to amoxicillin and ampicillin observed in the present study is consistent with the results of Adzitey et al. (2020), who reported that 86.0% of *S. enterica* isolates from cow's milk and dairy products in Ghana were susceptible to ampicillin. Similarly, Moraes et al. (2024) found that 95.6% of *S. enterica* isolates from commercial laying hen farms in Brazil were susceptible to ampicillin. In contrast, different studies from different regions have reported higher levels of ampicillin resistance among foodborne *Salmonella* isolates, particularly in isolates from human samples (Mahmood et al., 2023; Kanat and Terzi Gulel, 2025). The differences in ampicillin resistance levels across the present study and previously reported studies likely reflected regional variations in antimicrobial usage and resistance patterns. The differences in ampicillin resistance levels between the present study and previously reported studies likely reflect regional variations in antimicrobial usage and resistance patterns. This variation in ampicillin resistance highlights the importance of conducting local antimicrobial-susceptibility testing of foodborne pathogens in Libya to inform food safety and public health programs.

Importantly, no *S. enterica* subsp. *enterica* isolates in the present study were fully resistant to imipenem; 66.7% were classified as susceptible, whereas 33.3% demonstrated intermediate susceptibility. The current finding serves as a cautionary indicator of potential treatment failures as antibiotic resistance continues to emerge. Correspondingly, Adzitey et al. (2025) reported that all *S. enterica* isolates in Ghana were susceptible to imipenem, and Kanat and Terzi Gulel (2025) found that all *Salmonella* spp. isolated from cow's milk and dairy products in Turkey were 100% susceptible to imipenem.

The current findings demonstrated variable resistance levels to different carbapenems, with *S. enterica* subsp. *enterica* isolates exhibiting resistance rates of 38.9% and 16.7% to meropenem and ertapenem, respectively. The observed resistance to meropenem contrasts with the findings of Listorti et al. (2022) in Italy, who reported that meropenem was the only antimicrobial agent to which no *Salmonella* strains exhibited resistance. The resistance to meropenem and ertapenem is concerning, as it indicates a potential decrease in the antibiotic efficacy. These findings are particularly concerning, as carbapenems are often the last treatment option for MDR infections (Adel et al., 2021). Moreover, 94.4% (17/18) of the isolates were highly resistant to neomycin. The current finding was contrasted with the findings of Kanat and Terzi Gulel (2025), who reported 100% susceptibility to neomycin among *S. enterica* isolates from cow's milk and dairy products in Turkey. Similarly, Mekonnen et al. (2022) in Ethiopia found that *S. enterica* isolates from fecal and cow's milk samples demonstrated a high susceptibility to the antimicrobial agents tested, including neomycin. The discrepancies in the results highlighted regional differences in antimicrobial use and resistance patterns, underscoring the need for localized surveillance of antibiotic resistance in foodborne pathogens.

Although the excessive use of aminoglycosides in veterinary and human medicine has led to a substantial rise in microbial resistance, these antibiotics remain useful for treating different bacterial infections (Wang et al., 2022). In the present study, low gentamicin resistance rates were observed (11.1%), consistent with a previous study in Egypt, which reported a resistance rate of 2.6% among *Salmonella* isolates (Elshebrawy et al., 2022). Notably, gentamicin plays an important role in routine monitoring systems for investigating resistance mechanisms in *Salmonella* species.

Fluoroquinolones and cephalosporins are considered first-line antimicrobials and are recommended for the treatment of salmonellosis. Consequently, resistance to these medicines has become a major public health concern (Li et al., 2020). However, the isolates examined in the present study did not exhibit resistance to fluoroquinolones or cephalosporins.

Among the fluoroquinolones, norfloxacin indicated the highest susceptibility rate (88.9%), followed by levofloxacin (61.1%) and ciprofloxacin (55.6%). The ciprofloxacin susceptibility rate in the present study (55.6%) was lower than that reported for *S. enterica* isolates from poultry carcasses in Brazil and Ghana, both of which demonstrated 100% susceptibility to ciprofloxacin (Panzenhagen et al., 2016; Adzitey et al., 2020). Conversely, the susceptibility rate observed in the current study was higher than that reported in India, where Mir et al. (2015) found a ciprofloxacin susceptibility rate of 46.87% in poultry-derived *S. enterica* isolates. Differences in ciprofloxacin susceptibility profiles might be attributed to variations in its use for therapeutic or prophylactic purposes across regions. Due to the increasing incidence of antimicrobial resistance, particularly against fluoroquinolones, cephalosporins have emerged as the primary treatments for *Salmonella* infections (Lamichhane et al., 2024). In the present study, *S. enterica* subsp. *enterica* isolates exhibited low resistance to cefotaxime (5.6%) and no resistance to cefepime (0%). In contrast, a study conducted in China reported higher resistance rates for cefotaxime (70.46%) and cefepime (58.72%) among *S. enterica* isolates (Ma et al., 2018).

All isolates in the present study were MDR (18/18, 100%), a level comparable to that reported by Ayichew et al. (2025), who found all *S. enterica* isolates to be MDR. In addition, a high prevalence of MDR *S. enterica* (50.9%) was reported in Poland (Wójcicki et al., 2022). However, the MDR rate observed in the present study was higher than that reported by Adzitey et al. (2025), who found that only 18.8% of *S. enterica* isolates were MDR. The MAR index of *S. enterica* subsp. *enterica* isolates in the present study varied, ranging from 0.1 to 0.6. Similarly, Adzitey et al. (2025) reported MAR indices ranging from 0.11 to 0.77 in *S. enterica* isolates. Furthermore, Durrani et al. (2024) observed MAR values ranging from 0.4 to 0.6, whereas previous studies reported that all tested *S. enterica* isolates had MAR indices greater than 0.2 (Mir et al., 2022; Fahmy et al., 2025). In contrast, Wójcicki et al. (2022) observed that the majority of *S. enterica* isolates demonstrated MAR indices below 0.3, with only a single isolate surpassing 0.5. The presence of isolates with MAR indices of 0.3, 0.5, and 0.6 in the current study highlighted the potential overuse or misuse of antibiotics and represented a significant public health concern, as such isolates may serve as reservoirs of multidrug resistance.

CONCLUSION

The presence of *Salmonella enterica* subsp. *enterica* in milk, dairy products, meat, and meat products indicated a potential public health concern in Libya, particularly because some dairy products are frequently consumed without adequate heat treatment. Contamination of foods derived from animal origin highlighted the risks associated with inadequate hygiene practices during processing, handling, and storage. The current findings revealed considerable antimicrobial resistance among the isolates examined, with all *S. enterica* strains exhibiting multidrug resistance. The presence of such multidrug-resistant phenotypes highlighted the potential spread of resistant foodborne pathogens through the food chain. Therefore, persistent surveillance of foodborne pathogens, enhanced hygienic practices during food production and distribution, proper heat treatment of dairy products, and the responsible use of antimicrobial agents are imperative to mitigate the risk of foodborne infections. Furthermore, consistent surveillance of antimicrobial susceptibility patterns of foodborne bacteria in Libya is essential to facilitate effective treatment strategies and enhance national food safety programs. The present study was limited by the relatively small number of *S. enterica* isolates and by its focus on foods collected from retail markets in Libya, which might not have fully reflected resistance patterns in other regions or across different food types. Furthermore, antimicrobial resistance profiles may fluctuate over time; consequently, the current results may not accurately predict future trends. Further studies with larger sample sizes, broader geographic coverage, and periodic monitoring are needed to confirm these findings and further understand the spread of multidrug-resistant strains.

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Authors' contributions

Salah Mohamed Azwai, Aboubaker Mohamed Garbaj, and Ibrahim Mohamed Eldaghayes were responsible for the conception and design of the study. Salah Mohamed Azwai, Aboubaker Mohamed Garrbaj, Jihan Ali Sherif, Samira Abd Farag, Salem Farhat Abureema, and Fatim Taher Gammoudi conducted the laboratory experiments and data collection. Salah Mohamed Azwai and Aboubaker Mohamed Garrbaj carried out the data analysis. The authors Salah Mohamed

Azwai, Aboubaker Mohamed Garrbaj, Ibrahim Mohamed Eldaghayes, Jihan ALi Sherif, Samira Abd Farag, Salem Farhat Abureema, and Fatim Taher Gammoudi contributed to the composition and revision of the manuscript. All authors reviewed and approved the final edition of the manuscript.

Availability of data and materials

All data produced during the study are relevant and included in this published article, and are accessible from the corresponding author upon reasonable request.

Competing interests

The authors declared that there is no conflict of interest.

Ethical considerations

All authors have reviewed ethical considerations, including plagiarism, consent to publish, misconduct, data fabrication and falsification, duplicate publication and submission, and redundancy. Furthermore, the authors did not utilize any artificial intelligence tools in data preparation, writing, or revision of the manuscript.

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