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Research Article

Biochemical and antibiotic resistance profile of *Salmonella* isolated from stool in N'Djamena, Chad: associated risk factors

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Abstract

*Salmonella i*s responsible for two types of infections: foodborne gastroenteritis and typhoid and paratyphoid fevers. The objective of this study was to investigate the biochemical profile and resistance to antibiotics commonly used to treat the different *Salmonella* serotypes circulating in the city of N'Djamena. Isolation and identification of *Salmonella* in stool samples were performed at the laboratory of the National University Reference Hospital (CHU-RN) using standard clinical microbiology techniques.

Of the 395 stool cultures performed, 17 (23.2%) *Salmonella* were isolated, among which the identified serotypes were: 5 (29.4%) *Salmonella* Typhi, 3 (17.6%) *Salmonella* Para Typhi A, 2 (11.7%) *Salmonella* Para Typhi B, 2 (11.7%) *Salmonella* Typhimurium, 2 (11.7%) *Salmonella* Enteritidis and 3 (17.6%) *Salmonella arizonae* respectively. Between the proportions of positive stool culture results in people with digestive disorders associated with symptoms (76.5%) (Group 1), and people with digestive disorders without signs of disease (23.5%) (Group 2), there is a significant difference in favor of group 1 ($p = 0.001$). The antibiotic efficacy test showed that 59% of *Salmonella* were resistant to aminopenicillins (ampicillin, amoxicillin), sulfamethoxazole-trimethoprim, nalidixic acid, and tetracycline. In contrast, 82% of *Salmonella* were susceptible to amoxicillin + clavulanic acid, ceftriaxone, ciprofloxacin, and imipenem.

This study not only identified the serotypes of *Salmonella*, but also highlighted an effective antibiotic therapy for the prevention of *Salmonella* involved in diarrheal diseases circulating in the city of N'Djamena in Chad.

Keywords: diarrhea, *Salmonella*, antibiotic, digestive troubles, N'Djamena, Chad.

INTRODUCTION

Salmonellosis is a disease caused by bacteria belonging to the Enterobacteriaceae family and the *Salmonella* genus. *Salmonella* is responsible for two main types of infections: foodborne gastroenteritis and typhoid and paratyphoid fevers. These are facultative anaerobic Gram-negative bacilli. The genus *Salmonella* currently comprises two species: *Salmonella enterica* or *enteritica*, subdivided into six subspecies (*Salmonella enterica* (I), *Salmonella salamae* (II), *Salmonella arizonae* (IIIa), *Salmonella diarizonae* (IIIb), *Salmonella houtenae* (IV), *Salmonella indica* (VI), and *Salmonella bongori*). The enterica (I) subspecies is the most common in warm-blooded animals and humans, containing pathogenic serotypes such as Typhimurium and Enteritidis. These subspecies are defined by biochemical and phenotypic criteria, then classified into more than 2600 distinct serotypes characterized by their somatic antigens "O", their flagellar antigens "H" and in some cases, by their virulence antigens "Vi"[1,2]. *Salmonella* infection mainly affects products of animal origin (eggs, meat, raw milk, poultry) but also plant-based products (fruits, poorly washed vegetables) and is transmitted orally, often via the ingestion of food contaminated by the excrement of healthy or infected carrier animals[3].

Salmonella arizonae (or *Salmonella enterica* subsp. *arizonae*) infection is a rare zoonosis in humans, affecting mainly young children and immunocompromised people, often through contact with reptiles (turtles, snakes) or their products, causing more serious infections such as meningitis or osteomyelitis; in turkey poults, it causes septicemia with high mortality. Symptoms in humans include fever, diarrhea, vomiting, and abdominal pain, but can progress to serious complications[4,5]. Typhoid and paratyphoid fevers are caused by strictly human *Salmonella* bacteria: *Salmonella* Typhi, *Salmonella* para Typhi A, and certain strains of *Salmonella* para Typhi B. After an incubation period of one to two weeks, a high fever of 39–40°C, headache, anorexia, abdominal pain with foul-smelling, ochre-colored diarrhea, and nausea appear. Splenomegaly, a rash, and the characteristic "typhos," a state of prostration[6,7]. Antibiotic resistance in *Salmonella* is a growing public health problem, with strains becoming multidrug-resistant to classes such as

fluoroquinolones, cephalosporins, and cotrimoxazole, making treatment more difficult. The mechanisms include mutation and gene acquisition on mobile genetic elements, often transmitted by plasmids, making antibiograms essential. Furthermore, inappropriate treatment can promote chronic carriage. The most widely known methods of combating typhoid fever include effective handwashing. Cooking at temperatures above 65°C destroys the bacteria, but good hygiene and adherence to the cold chain are essential to prevent infection, which manifests as gastroenteritis. Supplying water systems with pathogen-free water should be implemented to limit the risk of exposure. Furthermore, national epidemiological surveillance is necessary: monitoring circulating serotypes and antibiotic resistance, screening individuals with fever and digestive disorders, and identifying chronic and acute carriers of *Salmonella*. The TAB vaccine, poorly tolerated and whose efficacy has been much debated, is currently being replaced by the Typhim Vi© vaccine, which is better tolerated and has a protective rate (against *Salmonella* Typhi only) of 60% in endemic areas[7,8,9]. In Chad, a study contributing to the knowledge of *Salmonella* has been documented on the prevalence of *Salmonella*[10], but no study has been conducted on biochemical and phenotypic criteria. The objective of this study was to investigate the biochemical profile and resistance to antibiotics frequently used in our region to treat the different *Salmonella* serotypes (specific and non-adaptive) circulating in humans in the city of N'Djamena.

MATERIALS AND METHODS

Setting, Period, and Type of Survey

This study involved prospective, cross-sectional surveys conducted from August 3 to December 21, 2025, on living conditions and the screening of chronic and acute carriers of *Salmonella* in the city of N'Djamena. Stool samples were analyzed at the bacteriology laboratory of the National University Reference Hospital (CHU-RN) in N'Djamena. A pre-established data collection form containing items (sociodemographic, clinical, paraclinical, and therapeutic information) was also used.

Study population, Sampling

Volunteer participants (each having signed a written informed consent form) were recruited by convenience sampling at different stages of treatment to screen for *Salmonella* (specific and non-adaptive) in chronic and acute carriers of *Salmonella* in hospital and community settings among febrile individuals with digestive troubles (n=395), aged 2 to 61 years, divided into two groups:

Group 1: Individuals with digestive troubles associated with other symptoms (n=344), aged 2 to 61 years.

Group 2: Individuals with digestive troubles without other signs of the disease (n=51), aged 11 to 61 years.

Sample Size

Sampling will be random, based on Cochran's formula[11]:

$N = z^2p\ (1\text{-}p)/I^2$

N = Sample size

Z = precision level of 1.96 for a 95% confidence level

P = 26.4% prevalence of *Salmonella* obtained in 2014 by Bessimbaye[12], I = margin of error of 5%

$N = (1.96)^2 \times 0.26\ (1\text{-}0.26)/(0.05)^2 = 295$, but given the availability of participants, we continued to a sample size of 395 stool samples.

Antibiotic Selection

Antibiotics were selected based on their prescription for the treatment of salmonellosis in hospital and community settings.

Table 1: Antibiotics Selected for Susceptibility Testing

Category	Family	Antibiotic	Dose/disk
Antibiotic (Bio-Rad)	Beta-Lactams	Amoxicillin (AMX)	25 µg
		Ampicillin (AMP)	10 µg
		Amoxicillin + clavulanic acid (AMC)	20/10 µg
		Ceftriaxone (CRO)	30 µg
		Cefotaxime (CTX)	30 µg
		Imipenem (IMP)	10 µg
	Cyclins	Tetracycline (TET)	30 µg
	Fluroquinolone	Ciprofloxacin (CIP)	5 µg
	Quinolones	Nalidixic acid (NAL)	30 µg
	Sulfamides	Sulfamethoxazole-trimethoprim (SXT)	1,25 /23,75 µg
	5 famillies	10 antibiotics	

Quality control was performed using the reference strain E. coli ATCC 25922.

Stool culture and antibiogram

Salmonella isolation and identification were performed after inoculation of stool samples onto Hektoen agar (Bio-Rad®). After 18 to 24 hours of incubation in a 37°C incubator, green colonies with a black center on Hektoen agar were suspected of being *Salmonella*. The colonies were subcultured onto Mueller-Hinton (MH) agar for Gram staining, oxidase testing, and antigenic studies. Biochemical identification was performed using the API® 20 E gallery (Bio-Mérieux 20100). The agglutination test was performed according to the instructions of Kaufmann and White (Pilet et al., 1979) using anti-*Salmonella* sera (OMA (agglutinating groups A, B, D, E, L), OMB (agglutinating groups C, F, G, H), OMC, and Vi) and anti-flagellar sera (Bio-Rad®) for the detection of *Salmonella*[13,14].Culture of the inoculum on the API® 20 E gallery (Bio-Mérieux 20100) was performed for biochemical identification. The API® 20 E gallery is based on the principle of microtubule inoculum with a suspension that rehydrates the media. Incubation takes place at 37°C in an incubator for 24 hours, during which time biochemical reactions (decarboxylation, fermentation, deamination) occur, resulting in spontaneous colored products that are revealed by the addition of reagents. *Salmonella* identification is performed using the API® 20 E catalog. This catalog provides identification for a large number of profiles obtained using API® 20 E, thus ensuring high reliability in the interpretation of results. McFarland 0.5 inoculum was used to perform the antibiogram using conventional techniques (disc diffusion method or Kirby-Bauer technique)[15]. The reading of the diameters of the sensitivity of the antibiotic discs was carried out according to the recommendations of the Antibiogram Committee of the French Society of Microbiology[16,17].

Bacterial strain confirmation and antibiogram testing were performed using the Vitek® 2™ Compact 60 analyzer. The system includes the Vitek® 2 Compact instrument, a computer (workstation), and a printer. The software provided with the Vitek® 2 Compact system includes data analysis and management programs. A bidirectional computer interface automatically transfers results to the user's Laboratory Information System (LIS) and to various product and patient reports. A quality control system is available to validate a Vitek® 2 Compact system test kit. An Advanced Expert System™ (AES) (for clinical use) is available to allow systematic online validation of results and interpretation of resistance phenotypes identified by the antibiograms. The inoculum for bacterial isolation was prepared according to the standard procedure and operating instructions for the Vitek® 2 Compact. Using a dispenser, 3 mL of saline solution (Reference 1204, 500 mL, 0.45% NaCl) was dispensed into 5 mL tubes arranged in a tray. Then, using a Pasteur pipette, a bacterial colony was suspended in 3 mL of saline solution, thoroughly mixed, and its optical density was checked with DensiChek McFarland (0.5-0.63) McF. For each suspension, a biochemical identification and antibiogram were performed. A Gram (-) V1 221 pipette (0.5-250 µL) was used to dispense 145 µL of identification suspension into 3 mL of saline solution for antibiotic susceptibility testing (GN = Gram (-) and AST = Corresponding Antibiotic) for each identification. The biochemical identification and antibiotic susceptibility testing cards were inserted into the suspensions arranged in the cassette, and the entire assembly was placed in the Vitek2 analyzer. Once the cassette was in the Vitek2, the loading process was initiated, and the Vitek2 read the barcodes on each card before sealing it. After sealing, the identification cassette was removed, and the Vitek2 performed the analysis. Vitek2 gave the minimum inhibitory concentration of antibiotics according to the European Antibiogram Committee[17].

STATISTICAL ANALYSIS

Data were entered and analyzed using Microsoft Word and Excel. The relationship between the proportion and sociodemographic parameters in the study population was assessed using the chi-square test ($p \leq 0.05$). Odd ratio (OR) with 95% confidence intervals were used to determine the degree of association between infection and sociodemographic parameters.

Sociodemographic characteristics of the studied population

A total of 395 stool samples were collected in the city of N'Djamena for the detection of *Salmonella* by stool culture (coproculture), among them, 344 stools were collected from people suffering from digestive disorders associated with other symptoms (diarrhea, vomiting, headaches, skin rashes etc), and 51 stool samples were collected from people with digestive disorders but without other signs of the disease. Of the 395 people surveyed, there were 272 (69%) men and 123 (31%) women ($p = 0.001$, significant difference) in favor of the participation of men in the survey with a sex ratio of 1.84. The average age of the patients was 31.5 years with extremes ranging from 2 to 61 years.

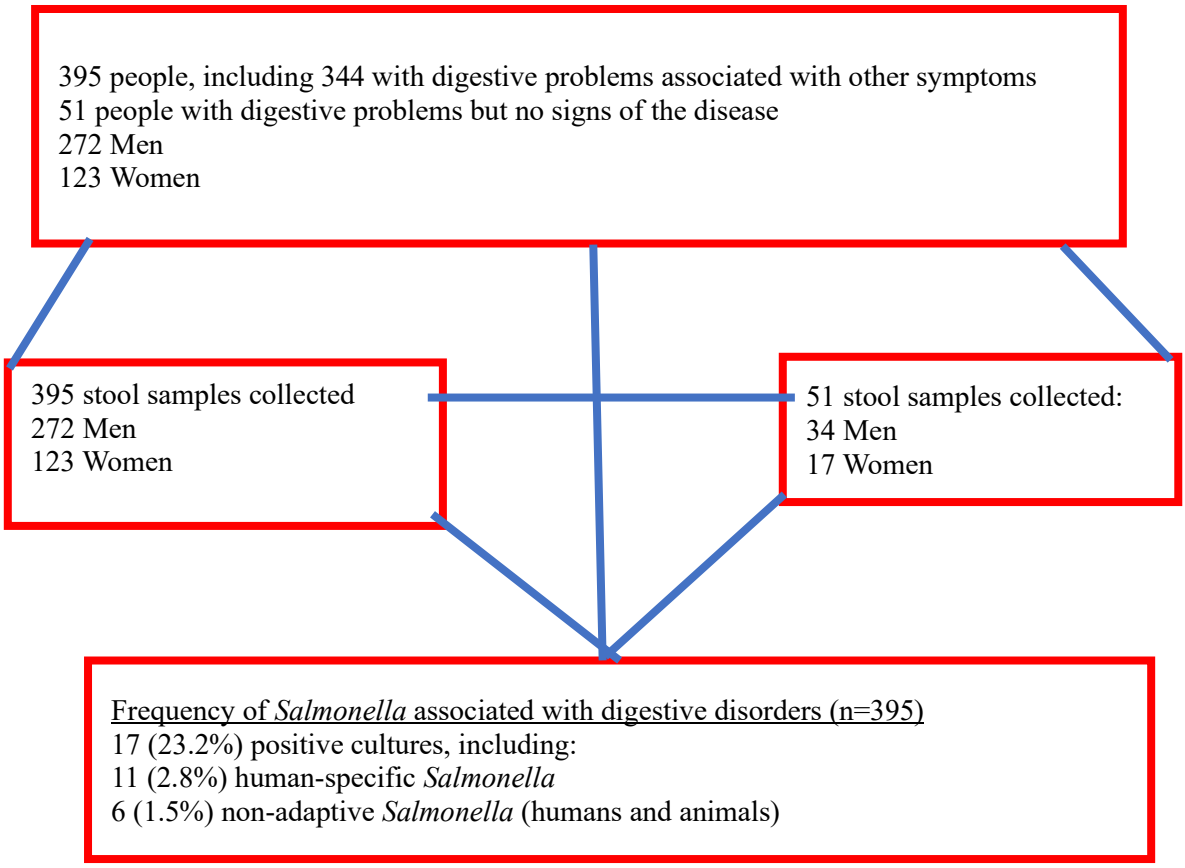


Figure 1: Sociodemographic characteristics of the studied population

Etiologies of *Salmonella* Isolated from Stool and Results of the Field Survey

Of the 395 stool cultures performed, 17 (23.2%) *Salmonella* were detected, including 11 (2.8%) *Salmonella* that specifically infect humans and 6 (1.5%) non-adaptive *Salmonella* that can infect both humans and animals. According to the survey, these salmonellosis infections are likely linked to poor food hygiene and are generally associated with diarrheal diseases. Furthermore, our study surveyed the most frequently prescribed antibiotics for the management of *Salmonella* infections in the city of N'Djamena, the capital of the Republic of Chad (Table 1). This survey revealed that Sulfamethoxazole-trimethoprim (SXT: Cotrimoxazole, commonly known as Bactrim) was prescribed in 60% of cases, followed by aminopenicillins (ampicillin, amoxicillin, amoxicillin + clavulanic acid), ceftriaxone (a third-generation cephalosporin: beta-lactam), and ciprofloxacin (a fluoroquinolone) and tetracycline, each used in over 40% of cases for the management of *Salmonella* infections. In most cases, the antibiotic therapy was not tailored to the antibiogram. The investigation also revealed that expired medications were being dumped in gutters around markets and in garbage heaps around homes.

Socio-demographic and clinico-biological characteristics of the studied population according to the presence of *Salmonella* isolated from stool

Table 2 shows that out of a total of 395 stool samples cultured, 17/395 (23.2%) *Salmonella* were isolated, of which 13/344 (3.8%) *Salmonella* were isolated from people suffering from digestive disorders associated with other symptoms (Group 1) and 4/51 (7.8%) from people with digestive disorders without other signs of the disease (Group 2). Of the 17 (23.2%) *Salmonella* isolated, 13/17 (76.5%) *Salmonella* were isolated from Group 1 and 4/17 (23.5%) *Salmonella* were isolated from Group 2 with a probability of 0.001 (significant difference in favor of Group 1) (table 2).

Table 2: Socio-demographic and clinico-biological characteristics of the studied population according to the presence of isolated *Salmonella*

Parameter	Group 1 (n1=344)	Group (n2=51)	*P*-value
Average age (year)	31.5 ± 1.41	36 ± 3.32	0.10
Men (%)	272 (69)	34 (66.7)	0.01
Women (%)	123 (31.1)	17 (33.3)	0.001
Sex-ratio (H/F)	1.84	1.84	0.00
Vomiting/Nausea (%)	13 (3.3)	-	0.00
Skin rashes (%)	16 (4.0)	-	0.00
Digestive troubles (%)	344 (100)	16 (29.4)	0.001
Fever (%)	151 (38.2)	-	0.00
Headaches (%)	171 (43.3)	-	0.00
Asthenia (%)	17 (4.3)	-	0.00
Positive stool cultures (n1, n2) (%)	13 (3.8)	4 (7.8)	0.00
Positive stool cultures (n) positive (%)	13 (76.5)	4 (23.5)	0.001

n=(n1+n2)=395 = effective; % = percentage

Distribution of *Salmonella* isolates by age group

Table 3 shows the distribution of *Salmonella* isolates by age group. Overall, 17/395 (23.2%) cultures (stool culture) were positive for *Salmonella* and 378 (96%) cultures were negative (p = 0.001, significant difference). The results in Table 3 also show that children aged 2 to 11, young people aged 12 to 21 and people over 42 were the most affected by *Salmonella* infections, whether specific to humans or both humans and animals (non-adaptive *Salmonella*). Seventeen (17) *Salmonella* isolated, among which the identified serotypes were: 5 (29.4%) *Salmonella* Typhi, 3 (17.6%) *Salmonella* Para Typhi A, 2 (11.7%) *Salmonella* Para Typhi B, 2 (11.7%) *Salmonella* Typhimurium, 2 (11.7%) *Salmonella* Enteritidis and 3 (17.6%) *Salmonella arizonae* (table 3).

Table 3: Distribution of *Salmonella* associated with diarrhea

***Salmonella* species**	**Age range (year)**				
	2-11	12-21	22-31	32-41	42 et plus
Human-specific Salmonella					
Salmonella Typhi	-	-	1	1	3
Salmonella Para Typhi A	1	2	-	-	-
Salmonella Para Typhi B	1	1	-	-	-
Total (%)	2 (18.2)	3 (27.3)	1 (9.1)	1 (9.1)	3 (27.3)
Non-adaptive *Salmonella* (humans, animals)					
Salmonella Typhimurium	1	-	-	-	1
Salmonella Enteritidis	1	-	-	-	1
Salmonella arizonae	1	1	-	-	1
Total (%)	3 (50)	1 (16,6)	-	-	2 (33,3)

Biochemical profile of *Salmonella* isolated from stool

Table 4 shows the characteristics of *Salmonella* isolated from stool by culture on an API 20E strip. The isolated *Salmonella* had the following common biochemical characteristics: ONPG-, Urea-, TDA-, Simmons Citrate+, Indole-, H2S+, ADH+/-, LDC+/-, ODC+, GLU+, MAN+, SOR+, RHA+, ARA+, and they were all motile and oxidase-negative. We observed that H2S was weakly positive after 24 hours of culture and more pronounced between 48 and 72 hours.

Table 4: Biochemical profile of isolated *Salmonella* from stool

	Carbohydrate																				
***Salmonella* strain**	ONPG	ADH	LDC	ODC	CIT	H_2S	URE	TDA	IND	VP	GEL	GLU	MAN	INO	SOR	RHA	SAC	MEL	AMY	ARA	OXY
Salmonella Typhi	-	+	+	+	+	+	-	-	-	-	-	+	+	+	+	+	-	-	-	+	-
Salmonella Para Typhi A	-	+	-	+	-	+	-	-	-	-	-	+	+	-	+	+	-	+	-	+	-
Salmonella Para Typhi B	-	-	+	+	+	+	-	-	-	-	-	+	+	-	+	+	-	+/-	-	+	-
Salmonella Typhimurium	-	+	+	-	-	+	-	-	-	-	-	+	+	-	+	+	-	+/-	-	+	-
Salmonella Enteritidis	-	+	+	+	+	+/-	-	-	-	-	-	+	+	-	+	+	-	+/-	-	+	-
Salmonella arizonae	-	-	+	+	+	+	-	-	-	-	+	+	+	-	+	+	-	-	-	+	-

+ = positive (carbohydrate utilization by the microorganism); - = negative (carbohydrate non-utilization by the microorganism); +/- = sometimes positive or negative; ONPG = Ortho-Nitro-Phenyl-Galactopyranosidase; ADH = Arginine Dihydrolase; LDC = Lysine Decarboxylase, ODC = Ornithine Decarboxylase; CIT = Simmons Citrate; H_2S = Dihydrogen Sulfide; Urea; TDA = Tryptophan Deaminase; IND = Indole; VP = Vogues-Proskauer; GEL = Gelatin; GLU = Glucose; MAN = Mannitol; INO = Inositol; SOR = Sorbitol; RHA = Rhamnose; SAC = Sucrose; MEL = Melibiose; AMY = Amygdalin; ARA = Arabinose; Ox = Oxidase

Susceptibility and resistance profile of *Salmonella* strains isolated from stool

Antibiotic efficacy testing showed that 59% of *Salmonella* strains were resistant to aminopenicillins (ampicillin, amoxicillin), sulfamethoxazole-trimethoprim, nalidixic acid, and tetracycline. In contrast, 82% of *Salmonella* strains were susceptible to amoxicillin + clavulanic acid, ciprofloxacin, ceftriaxone, and imipenem (table 5).

Table 5: Susceptibility and resistance profile of *Salmonella* strains isolated from stool

	Antibiotic																			
***Salmonella* strain**	**NbT**	AMP		AMX		AMC		CRO		IMP		CIP		NAL		TET		SXT	
		R	S	R	S	R	S	R	S	R	S	R	S	R	S	R	S	R	S
Salmonella Typhi	5	3	2	3	2	2	3	1	4	1	4	2	3	4	1	3	2	4	1
Salmonella Para Typhi A	3	2	1	2	1	1	2	1	2	1	1	1	2	1	2	2	1	1	2
Salmonella Para Typhi B	2	2	0	2	0	0	2	1	1	0	2	0	2	2	0	1	1	1	1
Salmonella Typhimurium	2	1	1	1	1	0	2	0	2	0	2	0	2	0	2	2	0	1	1
Salmonella Enteritidis	2	0	2	0	2	0	2	0	2	0	2	0	2	1	1	1	1	0	1
Salmonella arizonae	3	2	1	2	1	0	3	0	2	1	2	0	3	1	1	**1**	**2**	**2**	**1**
Total (%)	17	10 (59)	7 (41)	10 (59)	3 (41)	3 (18)	14 (82)	3 (18)	14 (82)	3 (18)	15 (82)	3 (18)	14 (82)	10 (59)	7 (41)	10 (59)	7 (41)	10 (59)	7N(41)

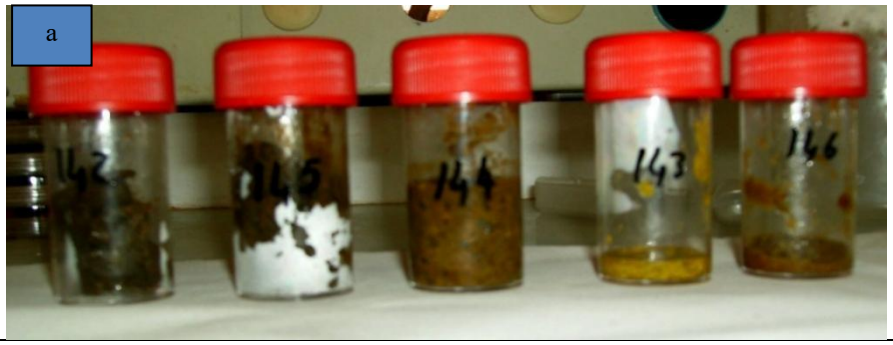
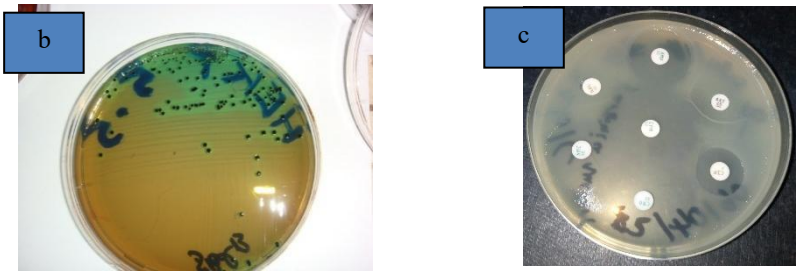
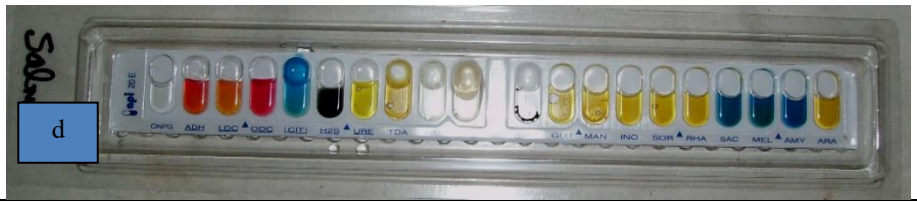
NbT = Number tested; Resistant = intermediate + resistant (I+R); Susceptible = S

Antibiotics: Sulfamethoxazole-trimethoprim (SXT: R < 10, 10 ≤ I ≤ 18, S ≥ 19); Ampicillin (AMP: R < 11, 11 ≤ I ≤ 14, S ≥ 14); Amoxicillin (AMX: R < 11, 11 ≤ I ≤ 16, S ≥ 17); Amoxicillin + clavulanic acid (AMC: R < 11, 11 ≤ I ≤ 16, S ≥ 17); Ceftriaxone (CRO: R<15, 15 ≤ I≤ 20, S≥ 21), Imipenem (IMP: R <22, 22≤ I≤25, S ≥25); Ciprofloxacin (CIP: R<21, S≥25); Nalidixic acid (NA: R< 21, S ≥ 25) Tetracycline (TET: R< 21, 21 ≤ I≤ 20, S ≥ 23). Quality control strains: *E. coli* ATCC® 25922, *E. coli* ATCC® 35218 and *Pseudomonas aeruginosa* ATCC® 27853 (CLSI®).

Morphological, biochemical, and antibiogram characteristics of *Salmonella* isolated from stool

Table 6 shows the morphological, biochemical, and antibiogram characteristics of *Salmonella* isolated from stool. Stool appearance (image: a) was: soft, formed, pasty, hard, and liquid. *Salmonella* colonies on Hektoen agar were green with a black center (image: b). The antibiogram (resistant (NAL, AMC, IMP, CRO), susceptible (AMP, SXT, CIP)) is shown in image c (Table 6). The biochemical profile of *Salmonella* Typhi is shown in the API20E gallery (image: d: table 6).

Table 6: Morphological, biochemical and antibiogram characteristics of *Salmonella* isolated from stool

1	a : different aspects of stools	
2	b : *Salmonella* Typhi colonies on Hectoen agar c : antibiogram	
3	d : *Salmonella* Typhi in culture on API 20E gallery	

DISCUSSION

In summary, the following question should be answered: have biochemical profiles, abusive and inappropriate prescriptions of antibiotics without laboratory evidence, or more generally, poor hygiene, and inadequate health infrastructure due to diagnostic tools contributed to the distribution and resistance of *Salmonella* to antibiotics in Chad?

The answer to this question would certainly require comparing our results regarding biochemical profiles, risk factors and antibiotic resistance with those of other authors, which could shed light on this subject.

In our study, 17/395 (23.2%) stool cultures were positive, including 11 (2.8%) human-specific *Salmonella* and 6 (1.5%) non-adaptive *Salmonella* (human and animal). The mean age of both groups in the study population was 31.5 years, with a range from 2 to 61 years. The sex ratio was 1.84, favoring male participation in the study. The age groups most affected by *Salmonella* infections were 2–11 years and 42 years and older, with infection rates of 50% and 33.3%, respectively. These results show that *Salmonella* involved in diarrheal diseases is linked to the consumption of raw or undercooked water or food (eggs, meat, poultry), but transmission could also be direct through contact with soiled hands and feces or urine. Furthermore, Dembélé et al. in Bamako (Mali) found a female predominance in their study population, Ka et al. in Senegal found a mean age of 39.93 years with a range of 15 to 72 years, and Okomé-Kouakou et al. (Gabon) identified the same causes of diarrhea, including a predominance of *Salmonella*[18,19,20,21].

The *Salmonella* species isolated in our study were divided into two groups into human-specific Salmonella (5 (29.4%) *Salmonella* Typhi, 3 (17.6%) *Salmonella* Para Typhi A, 2 (11.7%) *Salmonella* Para Typhi B) and non-adaptive *Salmonella* that infect humans and animals (2 (11.7%) *Salmonella* Typhimurium, 2 (11.7%) *Salmonella* Enteritidis and 3 (17.6%) *Salmonella arizonae*)) (table 3). *Salmonella* was the second most frequently identified pathogen in the studies by de Ka *et al*. in Senegal and Okome et al. in Gabon. In contrast to our series, Apetse et al. and d'Okome et al. had demonstrated that *Escherichia*

coli played a significant role in the bacterial etiologies of diarrhea[22,23,24].

Next, our study conducted a field survey on the most frequently prescribed antibiotics for the management of salmonellosis in the city of N'Djamena in Chad (table 1). This survey revealed that Sulfamethoxazole-trimethoprim (SXT: Cotrimoxazole, commonly known as Bactrim), aminopenicillins (ampicillin, amoxicillin, amoxicillin + clavulanic acid), ceftriaxone (3rd generation cephalosporin: Beta-lactams) and ciprofloxacin (Fluoroquinolones) were widely prescribed, accounting for more than 50% of salmonellosis cases. In most cases, the antibiotic therapy was not appropriate based on the antibiogram. Ciprofloxacin was the most frequently used antibiotic in cases of bacterial diarrhea (34.80%). There was no statistically significant relationship between isolated bacteria and the antibiotics used in bacterial diarrhea ($p > 0.05$)[25].

In view of the results of the survey on antibiotic therapy, which was mostly non-probabilistic, we carried out an evaluation of the effectiveness of the antibiotics identified (table 1), the results of which are recorded in Table 5. The antibiotic effectiveness test showed a resistance of 59% of *Salmonella* to aminopenicillins (ampicillin, amoxicillin), Sulfamethoxazole-trimethoprim, nalidixic acid and tetracycline. In contrast, 82% of *Salmonella* were susceptible to amoxicillin + clavulanic acid, ciprofloxacin, ceftriaxone, and imipenem (table 5). This increased resistance is likely due to the overuse and inappropriate prescribing of antibiotics by healthcare workers, as observed during our investigation. This resistance is also attributable to expired medications being dumped in gutters around markets and in garbage around homes. Cross-resistance was also observed in this family, with 2% (100%) *Salmonella* Para Typhi A exhibiting resistance to ampicillin, which in turn led to 2% (100%) *Salmonella* Para Typhi B exhibiting cross-resistance to amoxicillin (table 5). Such resistance, when observed, is thought to be linked to the production of penicillinase-like beta-lactamases by the strain in question (Yandai *et al*., 2014; Africa CDC, 2020)[22,23]. Our results could be explained by this phenomenon. Many strains, particularly *Salmonella* Typhimurium, exhibit high levels of antibiotic resistance, with nearly 40% of isolates resistant to at least one antibiotic and 18% multi-resistant[24,25,26]. *Salmonella* Typhi and *Salmonella* Para Typhi strains exhibit increased resistance to first-line antibiotics such as second-generation quinolones. In contrast, our study showed that 82% of the isolated *Salmonella* strains were susceptible to amoxicillin + clavulanic acid, ciprofloxacin, ceftriaxone, and imipenem (table 5). This susceptibility was also observed by Dembélé et al. (2022), Salah et al. (2017), and Reinheimer et al. (2017)[27,28].

CONCLUSION

The association of digestive troubles, *Salmonella*, and diarrhea is a daily and alarming concern, especially in cities of resource-limited countries like N'Djamena, where there are no drainage canals for wastewater, compounded by poor hygiene at street food sales points. Although this study was located in the city of N'Djamena, it identified diet-linked *Salmonella* that specifically infect humans (*Salmonella* Typhi, *Salmonella* Para Typhi A, *Salmonella* Para Typhi B) and non-adaptive *Salmonella* that infect both humans and animals (*Salmonella* Typhimurium, *Salmonella* Enteritidis and *Salmonella arizonae*). Furthermore, the isolated *Salmonella* strains are much more resistant to sulfamethoxazole-trimethoprim, ampicillin, amoxicillin, nalidixic acid, and tetracycline, further complicating the situation. The most susceptible antibiotics are amoxicillin + clavulanic acid, ciprofloxacin, ceftriaxone, and imipenem. Controlling these infections requires a concerted effort between the different actors (governments, the Ministry of Public Health and Prevention (MSPP) of Chad, basic humanitarian services and the population of the city of N'Djamena).

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Author Contributions: BN participated in the study design and supervised the work, as well as critically reviewing and editing the manuscript. DA and AM contributed to data collection and laboratory analysis. All authors have read and approved the final version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Ethical Approval Statement

To conduct this study, we obtained:

- ✓ Authorization from the Dean of the Faculty of Human Health Sciences (FSSH), University of N'Djamena, Chad;
- ✓ Authorization from the Director General of the Ministry of Public Health and Prevention (MSPP) of Chad;
- ✓ Authorization from the Director of the National University Referral Hospital (CHU-RN) of N'Djamena, Chad.

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