

***Salmonella enterica* isolates from poultry in North-Central Nigeria reveal multidrug-resistant patterns and risk of contamination to the human food chain**

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Abstract: Non-typhoidal (NT) salmonellosis is a major poultry-associated bacterial zoonosis. We undertook environmental sampling (poultry faeces and dust, $n = 600$) to evaluate the prevalence of NT *Salmonella* in poultry farms in North-Central Nigeria (NCN). Samples from five NCN states and Abuja were processed using standard bacterial culture and the *invA*-based PCR method, and isolates were tested against the 11 most used poultry antimicrobials by means of the Kirby–Bauer disk diffusion method. We measured inhibition zones using WHONET to classify resistance patterns. The overall prevalence rate was 18.7%, and prevalence rates in dust and faeces were 20.5% and 17.1%, respectively. Prevalence was lower in battery-caged birds, in flocks >1 000 birds, in older birds (>52 weeks, one year) and in layer farms. The odds of infection with NT *Salmonella* was $\geq$ twofold in younger birds. Isolates were most resistant to tetracycline (73.8%), nalidixic acid (59.5%) and sulphonamides (54.8%) and were most susceptible to ceftazidime (88.1%) and cefotaxime (78.6%). Single drug-resistant, multidrug-resistant, extensively drug-resistant and pandrug-resistant isolates were obtained, indicating abuse of antimicrobials in the poultry industry. Stricter control of access to antimicrobials will mitigate antimicrobial resistant pathogens, and inaction will complicate antimicrobial resistance in the human food chain with subsequent health and economic implications.

Keywords: antibacterial susceptibility; environmental contamination; food safety; livestock pathogens; zoonotic bacteria

Salmonellosis is a global pathogenic bacterial zoonosis with significant public, animal and environmental health effects (Ao et al. 2015; WHO 2015). The *Salmonella* serovars are broadly divided

into typhoidal *Salmonella* and non-typhoidal (NT) *Salmonella* serovars (Gal-Mor et al. 2014; Sanni et al. 2022). Both typhoidal and NT *Salmonella* can cause foodborne diseases, diarrhoea and as-

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sociated complications (Batz et al. 2012; Gal-Mor et al. 2014; Ao et al. 2015). In Nigeria, poultry-associated NT salmonellosis (NTS) is widespread and is spread by pathogens including *Salmonella enterica* subspecies *enterica* serovars Enteritidis and Typhimurium primarily, as well as other serovars such as Newport, Abadina, Schwarzengrund, Takoradi, Telegkebir, Kentucky, Poona, Isangi, Heidelberg, Saintpaul, Nigeria, Virchow, Laroche and Javiana among others (Feasey et al. 2012; Fagbamila et al. 2017; WHO 2018; Jibril et al. 2020). The farm-level prevalence of NTS in poultry may range from 39.7% to 48.3% (Fagbamila et al. 2017; Jibril et al. 2020). In various African countries, the prevalence of *Salmonella* in poultry has ranged from 12.1% to 100% (Ramtahal et al. 2022). These pathogens colonise poultry hosts and may carry asymptomatic infection, with consequent transmission to humans through the food chain or by contamination, especially the *S. enterica* serotypes Enteritidis and Typhimurium (Feasey et al. 2012; WHO 2018). For instance, the NT *S. enterica* infection has been confirmed as the pathogen with the largest burden of diarrhoeal disease and invasive infections globally (Kirk et al. 2015). In the United States, *Salmonella* remained the top-ranked foodborne pathogen, having the greatest economic and health effects among foodborne illnesses (Batz et al. 2011). In the European Union, NT *Salmonella* is the third leading cause of foodborne illness and accounts for most foodborne-associated deaths (WHO 2017).

In Africa, bacterial gastroenteritis has been identified as the most common disease, and there is a high burden of salmonellosis (Feasey et al. 2012; Kirk et al. 2015; Smith et al. 2016). According to a review, the overall prevalence of *Salmonella*-associated gastroenteritis in humans in Nigeria was 16.3%, and for *Salmonella*-associated bacteraemia, it was 1.9% (Akinyemi et al. 2021); furthermore, more than 53 *Salmonella* serotypes have been isolated from humans in Nigeria (Akinyemi et al. 2021). This prevalence in humans may have been underestimated, as health-seeking behaviour for non-rapidly fatal illnesses in formal health facilities is a last option only after self-treatment has failed (Uzochukwu and Onwujekwe 2004; Omolase et al. 2007; Wegbom et al. 2021).

Moreover, because the environment plays a huge role in the introduction and transmission of salmonellosis, critical evaluation of *Salmonella*

pathogens is important in poultry environments (Chinivasagam et al. 2009; Pal et al. 2022; Ramtahal et al. 2022). In this work, we collected poultry faeces and dust from poultry environments in North-Central Nigeria (NCN) and evaluated their potential to carry NTS, as well as their drug-resistant patterns.

MATERIAL AND METHODS

Study area

We conducted the study in NCN (Figure 1). With a human population of approximately 20 million, the region has a land mass of 242 425 km². The region had an estimated indigenous and exotic poultry population of 44 789 854 in 2020, which was approximately 20% of the poultry population in Nigeria (Sanni et al. 2022). To estimate exposure and outcome variables of *Salmonella* at the farm and state levels, we used cross-sectional sampling in layers and broilers from various farms in six ($n = 6$) states of NCN. Poultry farms in Nigeria raise birds using deep litter, battery cages, or a combination of both, depending on farm size, production type, and bird age (Adene and Oguntade 2008).

Faecal and dust sample collection

Faecal and dust samples were secured randomly from numerous spots in poultry pens into aseptic sample containers. Six hundred ($N = 600$) faecal and dust samples [300 (or 299) faecal samples, 300 (or 297) dust samples and 4 mixed samples] representing approximately 50 faecal and 50 dust samples from each state. The sample containers were labelled accordingly and transported on ice packs to the molecular biology laboratory of the Department of Veterinary Public Health and Preventive Medicine, Usmanu Danfodiyo University, Sokoto for microbiological analysis and susceptibility testing.

Salmonella isolation and identification

Culture evaluation of samples for the presence of *Salmonella* was performed in accordance with ISO 6579-1 (ISO 2022).

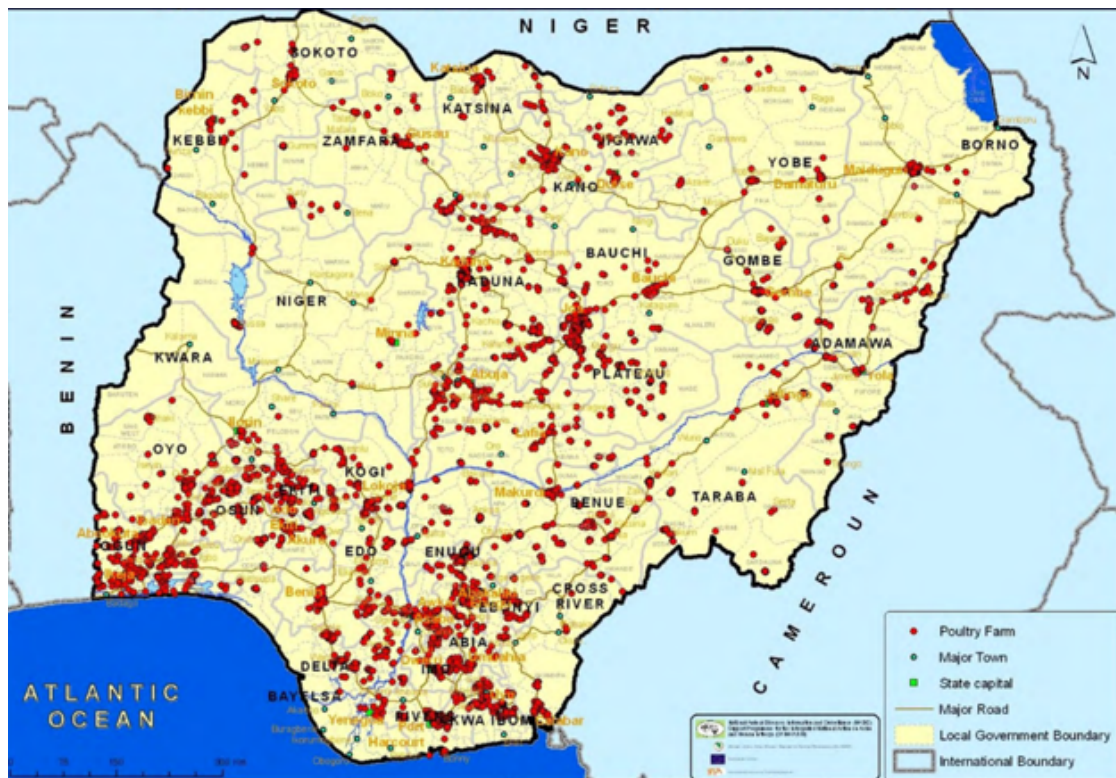


Figure 1. Rough spatial distribution of commercial poultry farms in Nigeria (2022)

The green square roughly represents the region where samples were collected from poultry farms

Source: Sonaiya et al. (2022)

Concisely, one gram (1 g) each of the faecal sample and the dust sample was weighed and introduced into 9 ml of buffered peptone water (Oxoid Ltd., Basingstoke, UK) for wide-reaching pre-enrichment of samples at 37 °C for 18 h to 24 hours. Subsequently, selective pre-enrichment was performed by transferring an aliquot of 0.1 ml of the suspension from the overnight culture mixture into 10 ml of Rappaport-Vassiliadis (RV) broth (Oxoid Ltd., Basingstoke, UK) overnight at 41.5 °C. Lastly, selective plating was performed from the RV mix in a parallel streaking on xylose lysine deoxycholate (XLD) agar (Oxoid Ltd., Basingstoke, UK) and subsequently onto Brilliance *Salmonella* Agar (BSA) (Oxoid Ltd., Basingstoke, UK) at 37 °C, and the plates were incubated overnight. The plates were thereafter examined for the presence of colonies with the black centre and pinkish background typical for *Salmonella* on XLD and BSA (Oxoid Ltd., Basingstoke, UK). For each sample unit, we collected one isolate from a pure culture and spiked it into selected samples for maintenance and quality control. We used *Salmonella* ATCC 14028 as the quality control strain.

Biochemical testing of presumptive *Salmonella* isolates was performed using commercially available Oxoid™ media: Simmons Citrate Agar (Oxoid CM0155), Sulphide Indole Motility (SIM) Medium (Oxoid CM0435), and Nutrient Agar (Oxoid CM0003) (Oxoid Ltd., Basingstoke, UK). A loopful of colonies was stabbed into Simmons Citrate Agar and SIM Medium and incubated at 37 °C overnight. Isolates showing positive citrate utilisation, hydrogen sulphide (H₂S) production, and motility but a negative indole reaction were categorised as presumptive *Salmonella*. We then subcultured these isolates onto Nutrient Agar and incubated them at 37 °C overnight.

PCR-based *Salmonella* identification

For further confirmation of *Salmonella*, we subjected isolates positive on the biochemical test to PCR identification using the *invA*-based method (Waghamare et al. 2018). Briefly, one to two bacterial colonies were suspended in 100 µl of molecular grade water (Gibco, Life Technologies, Grand

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Island, New York, USA) and subjected to boiling at 100 °C for 10 minutes. The mixture was centrifuged (Model 5910 R; Eppendorf AG, Hamburg, Germany) at 12 000 rpm (approximately 20 000 × *g*) for 2 minutes. The PCR mixture was prepared with Thermo Scientific™ PCR Master Mix (2X) (Cat. No. K0172; Thermo Fisher Scientific, Abingdon, Oxfordshire, UK) containing buffers, dNTPs, Taq DNA polymerase, reaction buffer and magnesium chloride. For the detection of *Salmonella*, PCR was performed in a 25-µl final volume containing 0.2 µM each of the *invA* forward primer (5'-GTGAAATTATCGCCACGTTCGGGCA-3') and the *invA* reverse primer (5'-TCATCGCACCGTCAAAGGAACC-3'). Both primers were used from 100 µM stock solutions. Amplification was performed using a thermal cycler (T100; Bio-Rad, Hercules, California, USA) at 95 °C for 5 min, 94 °C for 30 s, 63 °C for 30 s and 72 °C for 2 min for 35 cycles. We used a final cycle at 72 °C for 5 min (Rahn et al. 1992). We used imaging (GelDoc Go Imaging System; Bio-Rad, Hercules, California, USA) to visualise amplicons (PCR products), which were resolved by electrophoresis on a 1.5% (w/v) agarose gel prepared using UltraPure™ Agarose (Invitrogen™; Thermo Fisher Scientific, Waltham, MA, USA) in 1× TAE buffer. Isolates that showed a band size of 284 bp were considered *Salmonella* according to a 100-bp standard DNA ladder (TransGen Biotech, Beijing, P.R. China). We used the *Salmonella* ATCC 14028 reference strain as a positive control and water without DNA as a negative control.

Susceptibility testing of isolates

Because of budgetary constraints, we tested randomly selected isolates (stratified by state, farm type and sample matrix) from the culture-positive samples for antimicrobial susceptibility testing. We used the Kirby–Bauer disk diffusion method, as it is practical for routine surveillance in resource-limited settings and follows Clinical and Laboratory Standards Institute (CLSI) guidelines (CLSI 2020). However, we acknowledge that quantitative methods (e.g., broth microdilution) provide minimum inhibitory concentration values and greater precision; future studies should address this.

We subjected *S. enterica* isolates confirmed with PCR to a panel of 11 commonly used antimicrobials: ampicillin (10 µg), gentamicin (10 µg), ciproflox-

acin (5 µg), chloramphenicol (30 µg), cefotaxime (30 µg), ceftazidime (10 µg), kanamycin (30 µg), sulphonamides (300 µg), trimethoprim (5 µg), tetracycline (30 µg) and nalidixic acid (30 µg) (Oxoid Ltd., Basingstoke, UK). The tested antimicrobials covered seven classes: aminoglycosides (kanamycin and gentamicin), quinolones (nalidixic acid and ciprofloxacin), cepheims (cephalosporins I–IV, ceftazidime and cefotaxime), penicillins (ampicillin), tetracyclines (tetracycline), phenicols (chloramphenicol) and the folate pathway antagonists (sulphonamides and trimethoprim). We used the Kirby–Bauer disk diffusion method in accordance with the CLSI (2020). Specifically, to interpret the zone diameter breakpoints for most antimicrobials, we used CLSI M100 clinical breakpoints (CLSI 2020), and we consulted the CLSI M100 supplement (CLSI 2022) for confirmation of cephalosporin breakpoints, which did not alter the classification. We entered inhibition zones into WHONET v5.6 configured with the tested antimicrobials. We categorised isolates as susceptible, intermediate or resistant according to CLSI clinical breakpoints and CLSI guidelines for disk diffusion (CLSI 2022). We categorised strains that showed resistance to at least one drug in at least three different antimicrobial classes as multidrug-resistant (MDR), extensively drug-resistant (XDR) or pandrug-resistant (PDR) bacteria according to the method used by Magiorakos et al. (2012).

Data analysis

On the basis of *S. enterica* confirmed using culture and biochemical tests, we calculated the exact measure of association by using 2 × 2 table statistics in OpenEpi v3.03a (Dean et al. 2013). We calculated the odds-based estimates and confidence limits according to the method of Martin and Austin (1991).

Ethical considerations

We notified poultry farmers of the need to collect poultry faecal samples and drag swabs of dust from their premises, and we obtained oral consent. The protocol for the work was part of the protocol and ethical approval of the Research Ethics Committee of the Faculty of Veterinary Science, University of Pretoria, with ethical Approval No. REC 142-22 (July 2023). We also got additional ap-

proval from the Federal University of Technology, Minna Ethical Review Committee with Approval No. 000030 (May 2022). The work was endorsed through a notification to the Veterinary Teaching Hospital of Usmanu Danfodiyo University, Sokoto. After we obtained the approvals, we collected faecal and dust samples from broiler and layer flocks of various ages.

RESULTS

Description of environmental samples

We collected a total of 600 samples: 102 (17.0%) each from Kogi and Nasarawa states, 100 (16.7%) each from Benue and Kwara and 98 (16.3%) each from Niger State and the Abuja Federal Capital Territory (Table 1). Almost half (49.8%) of the samples originated from faeces, and 49.5% were dust samples from the poultry environments, with 0.7% as mixed or unclassified samples (Table 1). We col-

lected these samples from birds housed in battery cages and high-rise buildings (36.3%), deep litter (63.2%) and unspecified types of houses (0.5%). According to bird type, 358 of the samples were from broilers (59.7%), 228 (38.0%) were from laying birds, and 10 (1.7%) were from noilers (a dual-purpose chicken breed, for both eggs and meat, developed for the Nigerian poultry sector) (Table 1). The remaining four flocks (0.7%) were not specified. Flock sizes ($n = 15$ –50 000) and ages (one week to three years) varied widely; the median flock size and age were 195 and 8 weeks, respectively. Using classical bacteriological culture and biochemical tests, we found that 112 of 600 (18.7%) samples were positive, including 61 from dust samples and 51 from faecal samples. We confirmed the positive samples by using the *invA*-based PCR method [Electronic Supplementary Material (ESM) Figure S1].

The disaggregated category level prevalence ranged from 14.7% for Kogi and Nasarawa states to 29.6% for Niger State (Table 1). The prevalence in the faeces (17.1%) was less than that in the dust

Table 1. Prevalence and odds of *Salmonella* culture positivity in poultry environmental samples by state, sample type, farm management system, flock size, bird type, and age in North-Central Nigeria

Samples (n)	Categories (n)	Positive, n (%)	Negative, n (%)	Odds ratio	CMLE ORs	P -value (two-tailed)
Sample state of origin (600)	Abuja (FCT) (98)	16 (16.3)	82 (83.7)	1.13	0.52, 2.47	0.76
	Benue (100)	19 (19.0)	81 (81.0)	1.36	0.64, 2.90	0.42
	Kwara (100)	18 (18.0)	82 (82.0)	1.27	0.60, 2.73	0.53
	Kogi (102)	15 (14.7)	87 (85.3)	1.0	Ref.	n.a.
	Nasarawa (102)	15 (14.7)	87 (85.3)	1.0	0.45, 2.20	1.00
	Niger (98)	29 (29.6)	69 (70.4)	2.42	1.21, 4.99	0.01
Sample type (596)	faeces (299)	51 (17.1)	248 (82.9)	1.0	Ref.	n.a.
	dust (297)	61 (20.5)	236 (79.5)	1.26	0.83, 1.90	0.28
Farm management type (596)	battery cages (218)	33 (15.1)	185 (84.9)	1.48	0.95, 2.33	0.08
	deep litter (378)	79 (20.9)	299 (79.1)	1.0	Ref.	n.a.
Flock size (580)	≤1 000 birds (410)	83 (20.2)	327 (79.8)	1.23	0.78, 1.99	0.38
	>1 000 birds (170)	29 (17.1)	141 (82.9)	1.0	Ref.	n.a.
Bird type or purpose (596)	broilers/noilers ¹ (368)	77 (20.9)	291 (79.1)	1.46	0.94, 2.28	0.09
	layers (228)	35 (15.4)	193 (84.6)	1.0	Ref.	n.a.
Age of birds (594)	≤one year (516)	104 (20.2)	412 (79.8)	2.21	1.07, 5.06	0.03
	>one year (78)	8 (10.3)	70 (89.7)	1.0	Ref.	n.a.

Bold values are significant

¹Noiler is a dual-purpose chicken breed (for both eggs and meat) developed by Amo Farm Sieberer Hatchery Ltd. (AFSH) in Nigeria

CMLE ORs = conditional maximum likelihood estimate of odds ratios; FCT = Federal Capital Territory; n.a. = not applicable; Ref. = reference

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(20.5%). A higher prevalence was obtained from the deep litter system (20.9%) than from the battery cages (15.1%) (Table 1). Farms with $\leq 1\,000$ birds had a higher prevalence (20.2%) than did farms with $>1\,000$ birds (17.1%), and poultry stock aged one year or younger had a higher prevalence (20.2%) than did those older than one year (10.3%) (Table 1).

Association of environmental samples with odds of culture positivity

Among the states sampled, Niger State had 2.4-fold odds of NT *Salmonella* culture positivity compared with the other states, and poultry

birds younger than one year had twofold odds of NT *Salmonella* culture positivity compared with birds older than one year. All other parameters were comparable with the references in the analysis (Table 1).

Antimicrobial resistance pattern

Of the 42 isolates tested with PCR and for antimicrobial susceptibility, only two (KWD_5 and KOD_106; 4.8%) showed no resistance to any antimicrobial, whereas 95.2% had resistance to at least one antimicrobial. More of the resistant organisms were from dust (24/40; 60%) than from faeces

Sample identification	Kanamycin (KM)	Nitrolic Acid (NA10)	Clarithromycin (CPR)	Cefotaxime (CTOX)	Spectinomycin (CN10)	Ampicillin (AMP10)	Tetracycline (TE10)	Ceftriaxone (CA210)	Chloramphenicol (C30)	Sulphonamides (S3300)	Trimethoprim (MS1)	Sample type	Production system	Flock size	Chicken type	Age in weeks
ABD_56												Dust	Deep Litter	500	Layers	48
KOF_107												Faecal	Battery Cage	100	Layers	22
ABD_89												Dust	Deep Litter	300	Broilers	1
KOD_95												Dust	Deep Litter	50	Broilers	9
NAD_22												Dust	Deep Litter	50	Broilers	8
NGF1_8												Faecal	Battery Cage	800	Layers	32
KOF_119												Faecal	Deep Litter	93	Broilers	5
KOD_126												Dust	Deep Litter	100	Broilers	2
NAD_32												Dust	Deep Litter	200	Broilers	8
KOD_106												Dust	Deep Litter	120	Broilers	5
KOF_95												Faecal	Deep Litter	50	Broilers	9
ABF_89												Faecal	Deep Litter	300	Broilers	1
BEJ_2												Dust	Deep Litter	25	Broilers	12
BEJ_11												Dust	Deep Litter	100	Broilers	5
BEJ_4												Dust	Deep Litter	150	Broilers	4
KWD_43												Dust	Deep Litter	8500	Broilers	5
KWD_5												Dust	Battery Cage	12500	Layers	56
KWF_36												Faecal	Battery Cage	5000	Layers	12
KWD_27												Dust	High rise	37000	Layers	6
KWF_28												Faecal	High rise	51000	Layers	6
KWD_36												Dust	Battery Cage	9000	Layers	12
KWF_39												Faecal	Battery Cage	14500	Layers	21
KWD_6												Dust	Battery Cage	6250	Layers	32
KWD_24												Dust	Battery Cage	31000	Layers	30
KWD_17												Dust	Battery Cage	8230	Broilers	8
KWD_32												Dust	Battery Cage	20104	Layers	14
KWD_22												Dust	Battery Cage	2330	Layers	11
KWF_40												Faecal	Battery Cage	8500	Layers	13
KWF_45												Faecal	Deep Litter	9550	Broilers	21
NGD1_33												Dust	Deep Litter	300	Broilers	2
NGF1_50												Faecal	Deep Litter	50	Broilers	8
NGF1_41												Faecal	Battery Cage	130	Layers	27
NGF1_16												Faecal	Deep Litter	60	Broilers	6
NGF1_43												Faecal	Deep Litter	100	Broilers	3
NGF1_18												Faecal	Deep Litter	147	Broilers	2
NGD1_36												Dust	Deep Litter	50	Broilers	4
NGD1_23												Dust	Deep Litter	50	Broilers	2
NGD1_34												Dust	Deep Litter	100	Broilers	3
NGF1_38												Faecal	Deep Litter	200	Broilers	4
NGD1_58												Dust	Deep Litter	200	Broilers	4
NGD1_28												Dust	Deep Litter	25	Broilers	7
NGD2_25												Dust	Deep Litter	100	Broilers	5

Figure 2. Heat map of antimicrobial resistance patterns of *Salmonella* isolates recovered from poultry farms in North-Central Nigeria

Red colour = resistant; Orange colour = intermediate; Green colour = susceptible

Table 2. Antimicrobial resistance, intermediate, and susceptibility profiles of *Salmonella* isolates from poultry farms in North-Central Nigeria

Tested antimicrobial	Kanamycin (K30)	Nalidixic acid (NA30)	Ciprofloxacin (CIP)	Cefotaxime (CTX30)	Gentamicin (CN10)	Ampicillin (AMP10)	Tetracycline (TE30)	Ceftazidime (CAZ10)	Chloramphenicol (C30)	Sulphonamides (S3'300)	Trimethoprim (W5)
Resistant	35.7	59.5	47.6	11.9	28.6	42.9	73.8	2.4	33.3	54.8	45.2
Intermediate	14.3	23.8	11.9	9.5	14.3	2.4	4.8	9.5	9.5	2.4	0.0
Susceptible	50.0	16.7	40.5	78.6	57.1	54.8	21.4	88.1	57.1	42.9	54.8

(16/40; 40%) (Figure 2). In addition, 35% of the resistant *Salmonella* samples were from laying flocks, and 65% were from broilers. The prevalence of antimicrobial resistance (AMR) in organisms was independent of farm size (minimum = 25; median = 200; maximum = 37 000), age of the chicken flock (minimum = 1 week; median = 7.5 weeks; maximum = 56 weeks), or state in NCN (Figure 2). Furthermore, although we had four ($n = 4$) single antimicrobial-resistant isolates, we obtained several MDR and XDR isolates, as well as a PDR isolate (ABF_89) (Figure 2). The isolates were most resistant to tetracycline (TE30) (73.8%), followed by nalidixic acid (NA30) (59.5%), sulphonamides (S3'300) (54.8%), ciprofloxacin (CIP) (47.6%), trimethoprim (W5) (45.2%), ampicillin (AMP10) (42.9%), kanamycin (K30) (35.7%), chloramphenicol (C30) (33.3%) and gentamicin (CN10) (28.6%), and most susceptible to ceftazidime (CAZ10) (88.1%) and cefotaxime (CTX30) (78.6%) (Figure 2, Table 2).

DISCUSSION

In this work, a total of 600 environmental samples (faeces and dust) were collected from NCN and analysed with an overall prevalence of 18.7% (112/600). NTS prevalence was similar across states, except in Niger State, which had a much higher prevalence and higher odds of NTS isolation in poultry farms. Although the immediate cause of this spatial distribution is unknown, the proliferation of unregulated marketing and hatchery services, and the distribution from them, may have led to dispersing poultry- and hatchery-associated NTS widely. Such observations have been made in other African countries (Ipara et al.

2019; RADARR Africa 2022). Jibril et al. (2020) and Samper-Cativiela et al. (2023) earlier confirmed that relatively higher prevalence is detected in older layer flocks (>83 weeks) compared with younger flocks. This finding contrasts with ours: we observed higher prevalence and greater odds of *Salmonella* positivity in younger flocks than in older ones (note that broilers are slaughtered between 6 and 12 weeks, whereas layer flocks stay on the farm much longer than a year).

Although poultry and poultry products have been implicated as a major source of NTS for poultry farm infection and contamination of the human food chain (Wang et al. 2023), our results showed that the dust in the poultry environment may serve as a higher source of infection than poultry faeces. This finding is consistent with previous findings of Chinivasagam et al. (2009), Pal et al. (2021) and Pal et al. (2022).

Similarly, although this finding was not significant, we observed a slightly higher prevalence in the deep litter system than in the battery cages. This finding is consistent with Jibril et al. (2020). However, results from a number of studies have also confirmed that poultry raised in battery cages may have higher odds of shedding *Salmonella* organisms (Van Hoorebeke et al. 2011). Farms with $\leq 1\,000$ birds had a higher prevalence (20.2%) than did farms with $>1\,000$ birds (17.1%), and poultry stock aged one year or younger had a higher prevalence (20.2%) than did those older than one year (10.3%) (Table 1).

The pattern of resistance observed in this study aligns closely with findings in previous reports on the use of antimicrobials in livestock farming in Nigeria, which have confirmed that the most used and abused antimicrobials in the poultry sector in Nigeria include tetracycline, tylosin, chloram-

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phenicol, metronidazole, ciprofloxacin, gentamicin and colistin (Adesokan et al. 2015; Oloso et al. 2019; Adebowale et al. 2020; Oloso et al. 2020; Adebowale et al. 2022; Odey et al. 2024). Similar patterns of antimicrobial use and abuse prevail in other parts of Africa (Gemedā et al. 2020; Gebeyehu et al. 2021; Mdegela et al. 2021; Paintsil et al. 2021). Only two of the 42 isolates were susceptible to all antimicrobial classes tested, four were resistant to one antimicrobial, and the remaining 36 (85.7%) showed multiple resistance across antimicrobial classes. Without change, multidrug resistance will continue to predominate in the poultry and other livestock sectors, leading to many infections that are difficult to treat in the livestock industry. The implications include potential higher rates of morbidity and mortality, reduced productivity, complications and long-term health impacts, treatment challenges, and increasing health costs, among others. Furthermore, given that these are production animals, they may likely pass resistant pathogens through the human food chain. The results of this work call for another look at the policies and guidelines guiding antimicrobial use and surveillance in poultry and general livestock production, along with the need for intensified efforts for stringent control of access to these antimicrobials.

Epidemiological context of *Salmonella* infections in Africa

This study's findings align with a growing body of evidence indicating that NTS remains a persistent challenge across African poultry systems. Studies from western, eastern and southern Africa have reported farm-level prevalence rates ranging from 12.1% to 48.3%, with considerable variation driven by differences in biosecurity, husbandry practices and antimicrobial use (Fagbamila et al. 2017; Jibril et al. 2020; Ramtahal et al. 2022).

In particular, high prevalence has been documented in free-range and semi-intensive systems, where contact with wildlife and contaminated environments is more difficult to control (Mdegela et al. 2021; Paintsil et al. 2021). These regional patterns underscore that *Salmonella* contamination is not merely a farm-level issue but a systemic one, influenced by supply chains, unregulated hatcheries and limited veterinary oversight (Ipara et al. 2019; RADARR Africa 2022).

Public health and economic significance

The importance of controlling NTS in poultry extends beyond animal health. In sub-Saharan Africa, NTS is a leading cause of invasive bacterial disease among young children, adults with HIV and other immunocompromised populations, with case fatality rates reaching 20% to 25% in some settings (Feasey et al. 2012; Ao et al. 2015). Unlike in high-income countries where NTS typically manifests as self-limiting gastroenteritis, invasive NTS in Africa is often a bloodstream infection requiring prompt, effective antibiotic therapy. The emergence of MDR and XDR NTS strains, as observed in our study, threatens to render empirical treatments ineffective, potentially increasing mortality and treatment costs (Kirk et al. 2015; Akinyemi et al. 2021). Economically, the burden of foodborne salmonellosis reduces productivity, increases healthcare expenditure and harms trade in poultry products – a sector that supports millions of livelihoods across the continent (Odey et al. 2024).

Actionable recommendations for policy and practice

On the basis of these findings and the broader regional context, we propose the following specific interventions to reduce NTS prevalence and limit the spread of AMR from poultry environments to the human food chain:

1. Establishment of farm-level biosecurity audits – Routine, low-cost audits (e.g., checking cleaning protocols, visitor access and separation of age groups) should be implemented and linked to certification for market access. Pilot programmes in Nigeria have shown that structured biosecurity scoring can reduce detected *Salmonella* by up to 40% (Sanni et al. 2022).
2. Regulation of antimicrobial access through veterinary prescription only – Currently, many antimicrobials (including tetracyclines, fluoroquinolones and aminoglycosides) are obtainable over the counter without veterinary consultation. Enforcing prescription-only access, supported by training of agro-veterinary drug sellers, would directly reduce the selective pressure driving the high resistance rates observed in this study (Adesokan et al. 2015; Oloso et al. 2020).

3. Routine environmental monitoring of poultry dust as a sentinel surveillance target – Our results showed that dust samples had slightly higher prevalence (20.5%) than faeces (17.1%) and were a rich source of resistant isolates. Swabbing of settled dust is a non-invasive, low-cost method that can be scaled for AMR surveillance at regional or national levels, providing early warning of emerging resistance before clinical outbreaks occur (Pal et al. 2021; Pal et al. 2022).
4. Farmer education programmes on antimicrobial stewardship – Targeted extension services should deliver practical training on proper drug use, withdrawal periods and alternatives such as probiotics and improved hygiene. Farmer field schools, successfully deployed in East Africa for mastitis control, could be adapted to reduce AMR in poultry (Gemedo et al. 2020; Gebeyehu et al. 2021).

Implementing these measures will require co-ordinated action by veterinary authorities, agricultural extension services and poultry industry associations. Without such action, the continued misuse of antimicrobials will accelerate the spread of antimicrobial-resistant *Salmonella* through the food chain, with lasting health and economic consequences for Nigeria and the wider region.

We acknowledge the limitation of this study: The antimicrobial susceptibility breakpoints used were derived from CLSI M100 (CLSI 2020), which is intended for human clinical isolates. Specific veterinary breakpoints for poultry pathogens are not yet available for all antimicrobials tested. Where veterinary-specific breakpoints exist (e.g., for tetracycline and ampicillin in poultry), we cross-referenced them and found no change in classification for our isolates. However, for consistency, we retained human breakpoints, a common practice in livestock AMR surveillance in Africa (Ramtahal et al. 2022; Odey et al. 2024). Future studies should apply veterinary-specific breakpoints as they become available.

This work highlighted key findings for Nigeria's poultry sector. First, salmonellosis, especially NTS, is still prevalent in Nigerian poultry farms. Although the national mean prevalence rate is $\approx 25\%$, prevalences in NCN varied between 14.7% and 29.6%, regardless of housing type. Second, both poultry and the poultry environment can contaminate other farms and the human food chain; therefore,

we need to be more circumspect when handling poultry, poultry litter, and their byproducts.

The use and abuse of antimicrobials appears to be driving the increasing risk of AMR, as the resistance pattern generated in this work closely matched the antimicrobials used most prevalently in the field, indicating the need for authorities to implement stricter control on access to antimicrobials; otherwise, we risk the introduction of antimicrobial-resistant pathogens into the human food chain with the subsequent health and economic implications. Finally, this work provides empirical evidence for makers and implementers of policy on controlling NTS in Nigeria.

Conflict of interest

The authors declare no conflict of interest.

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REFERENCES

- Adebawale O, Makanjuola M, Bankole N, Olasaju M, Alamu A, Kperegbeyi E, Oladejo O, Fasanmi O, Adeyemo O, Fasina FO. Multi-drug resistant *Escherichia coli*, biosecurity and anti-microbial use in live bird markets, Abeokuta, Nigeria. *Antibiotics* (Basel). 2022 Feb 16;11(2):253.
- Adebawale OO, Adeyemo FA, Bankole N, Olasaju M, Adesokan HK, Fasanmi O, Adeyemo O, Awoyomi O, Kehinde O, Fasina FO. Farmers' perceptions and drivers of antimicrobial use and abuse in commercial pig production, Ogun State, Nigeria. *Int J Environ Res Public Health*. 2020 May 20;17(10):3579.
- Adene DE, Oguntade AE. Poultry sector country review – Nigeria [Internet]. Rome: FAO Animal Production and

<https://doi.org/10.17221/76/2025-VETMED>

- Health Division; 2008 Apr [cited 2026 Feb 8]. 95 p. Available from: www.fao.org/3/ai352e/ai352e.pdf.
- Adesokan HK, Akanbi IO, Akanbi IM, Obaweda RA. Pattern of antimicrobial usage in livestock animals in south-western Nigeria: The need for alternative plans. *Onderstepoort J Vet Res*. 2015 Apr 16;82(1):816.
- Akinyemi KO, Ajoseh SO, Fakorede CO. A systemic review of literatures on human *Salmonella enterica* serovars in Nigeria (1999–2018). *J Infect Dev Ctries*. 2021 Sep 30;15(9):1222–35.
- Ao TT, Feasey NA, Gordon MA, Keddy KH, Angulo FJ, Crump JA. Global burden of invasive nontyphoidal *Salmonella* disease, 2010. *Emerg Infect Dis*. 2015 Jun;21(6):941–9.
- Batz MB, Hoffmann S, Morris JG Jr. Ranking the risks: The 10 pathogen-food combinations with the greatest burden on public health [Internet]. Gainesville (FL): Emerging Pathogens Institute, University of Florida; 2011 Apr [cited 2025 Oct 18]. 70 p. Available from: archives.indiana.edu/items/19646b57-9efa-491d-b85c-0c03fe922f8b.
- Batz MB, Hoffmann S, Morris JG Jr. Ranking the disease burden of 14 pathogens in food sources in the United States using attribution data from outbreak investigations and expert elicitation. *J Food Prot*. 2012 Jul;75(7):1278–91. Erratum in: *J Food Prot*. 2012 Aug;75(8):1366.
- Chinivasagam HN, Tran T, Maddock L, Gale A, Blackall PJ. Mechanically ventilated broiler sheds: A possible source of aerosolized *Salmonella*, *Campylobacter*, and *Escherichia coli*. *Appl Environ Microbiol*. 2009 Dec;75(23):7417–25.
- CLSI – Clinical and Laboratory Standards Institute. Performance standards for antimicrobial susceptibility testing. 30th ed. CLSI supplement M100. Wayne (PA): CLSI; 2020. p. 32–41.
- CLSI – Clinical and Laboratory Standards Institute. Performance standards for antimicrobial susceptibility testing. 32nd ed. CLSI supplement M100. Wayne (PA): CLSI; 2022.
- Dean AG, Sullivan KM, Soe MM. OpenEpi: Open source epidemiologic statistics for public health [computer software]. Version 3.03a. 2013. Available from: www.OpenEpi.com.
- Fagbamila IO, Barco L, Mancin M, Kwaga J, Ngulukun SS, Zavagnin P, Lettini AA, Lorenzetto M, Abdu PA, Kabir J, Umoh J, Ricci A, Muhammad M. *Salmonella* serovars and their distribution in Nigerian commercial chicken layer farms. *PLoS One*. 2017 Mar 9;12(3):e0173097.
- Feasey NA, Dougan G, Kingsley RA, Heyderman RS, Gordon MA. Invasive non-typhoidal salmonella disease: An emerging and neglected tropical disease in Africa. *Lancet*. 2012 Jun 30;379(9835):2489–99.
- Gal-Mor O, Boyle EC, Grassl GA. Same species, different diseases: How and why typhoidal and non-typhoidal *Salmonella enterica* serovars differ. *Front Microbiol*. 2014 Aug 4;5:391.
- Gebeyehu DT, Bekele D, Mulate B, Gugsu G, Tintagu T. Knowledge, attitude and practice of animal producers towards antimicrobial use and antimicrobial resistance in Oromia zone, north eastern Ethiopia. *PLoS One*. 2021 May 12;16(5):e0251596.
- Gemeda BA, Amenu K, Magnusson U, Dohoo I, Hallenberg GS, Alemayehu G, Desta H, Wieland B. Antimicrobial use in extensive smallholder livestock farming systems in Ethiopia: Knowledge, attitudes, and practices of livestock keepers. *Front Vet Sci*. 2020 Feb 26;7:55.
- Ipara BO, Otieno DO, Nyikal RA, Makokha SN. The role of unregulated chicken marketing practices on the frequency of Newcastle disease outbreaks in Kenya. *Poult Sci*. 2019 Dec 1;98(12):6356–66.
- ISO – International Organization for Standardisation. ISO 6579-1:2017/AMD 1:2022: Microbiology of the food chain – Horizontal method for the detection, enumeration and serotyping of *Salmonella*. Part 1: Detection of *Salmonella* spp. [Internet]. Geneva: ISO; 2022 Feb [cited 2024 Dec 15]. 50 p. Available from: www.iso.org/standard/56712.html.
- Jibril AH, Okeke IN, Dalsgaard A, Kudirkiene E, Akinlabi OC, Bello MB, Olsen JE. Prevalence and risk factors of *Salmonella* in commercial poultry farms in Nigeria. *PLoS One*. 2020 Sep 23;15(9):e0238190.
- Kirk MD, Pires SM, Black RE, Caipo M, Crump JA, Devleeschauwer B, Dopfer D, Fazil A, Fischer-Walker CL, Hald T, Hall AJ, Keddy KH, Lake RJ, Lanata CF, Torgerson PR, Havelaar AH, Angulo FJ. World Health Organization estimates of the global and regional disease burden of 22 food-borne bacterial, protozoal, and viral diseases, 2010: A data synthesis. *PLoS Med*. 2015 Dec 3;12(12):e1001921. Erratum in: *PLoS Med*. 2015 Dec 23;12(12): e1001940.
- Magiorakos AP, Srinivasan A, Carey RB, Carmeli Y, Falagas ME, Giske CG, Harbarth S, Hindler JF, Kahlmeter G, Olsson-Liljequist B, Paterson DL, Rice LB, Stelling J, Struelens MJ, Vatopoulos A, Weber JT, Monnet DL. Multidrug-resistant, extensively drug-resistant and pan-drug-resistant bacteria: An international expert proposal for interim standard definitions for acquired resistance. *Clin Microbiol Infect*. 2012 Mar;18(3):268–81.
- Martin D, Austin H. An efficient program for computing conditional maximum likelihood estimates and exact confidence limits for a common odds ratio. *Epidemiology*. 1991 Sep;2(5):359–62.
- Mdegela RH, Mwakaheje ER, Rubegwa B, Gebeyehu DT, Niyigena S, Msambichaka V, Nonga HE, Antoine-Mous-

<https://doi.org/10.17221/76/2025-VETMED>

- siaux N, Fasina FO. Antimicrobial use, residues, resistance and governance in the food and agriculture sectors, Tanzania. *Antibiotics* (Basel). 2021 Apr 16;10(4):454.
- Odey TOJ, Tanimowo WO, Afolabi KO, Jahid IK, Reuben RC. Antimicrobial use and resistance in food animal production: Food safety and associated concerns in Sub-Saharan Africa. *Int Microbiol*. 2024 Feb;27(1):1-23.
- Oloso NO, Adeyemo IA, van Heerden H, Fasanmi OG, Fasina FO. Antimicrobial drug administration and antimicrobial resistance of *Salmonella* isolates originating from the broiler production value chain in Nigeria. *Antibiotics* (Basel). 2019 Jun 6;8(2):75.
- Oloso NO, Smith PW, Adeyemo IA, Odetokun IA, Isola TO, Fasanmi OG, Fasina FO. The broiler chicken production value chain in Nigeria between needs and policy: Situation analysis, action plan for development, and lessons for other developing countries. *CAB Rev*. 2020 May; 15:020.
- Omolase CO, Adeleke OE, Afolabi AO, Afolabi OT. Self medication amongst general outpatients in a Nigerian community hospital. *Ann Ib Postgrad Med*. 2007 Dec; 5(2):64-7.
- Paintsil EK, Ofori LA, Akenten CW, Fosu D, Ofori S, Lamshoft M, May J, Danso KO, Krumkamp R, Dekker D. Antimicrobial usage in commercial and domestic poultry farming in two communities in the Ashanti Region of Ghana. *Antibiotics* (Basel). 2021 Jun 30;10(7):800.
- Pal A, Bailey MA, Talorico AA, Krehling JT, Macklin KS, Price SB, Buhr RJ, Bourassa DV. Impact of poultry litter *Salmonella* levels and moisture on transfer of *Salmonella* through associated in vitro generated dust. *Poult Sci*. 2021 Aug;100(8):101236.
- Pal A, Jackson AP, Urrutia A, Macklin KS, Price SB, Buhr RJ, Bourassa DV. Research note: Bacterial composition of settled dust during growout of broiler chickens. *Poult Sci*. 2022 Feb;101(2):101602.
- RADARR Africa. Poultry farmers calling to government to crackdown unregulated poultry hatcheries [Internet]. 2022 Oct 26 [cited 2024 Mar 3]. Available from: radarr.africa/poultry-farmers-calling-to-government-to-crackdown-unregulated-poultry-hatcheries/.
- Rahn K, De Grandis SA, Clarke RC, McEwen SA, Galan JE, Ginocchio C, Curtiss R 3rd, Gyles CL. Amplification of an *invA* gene sequence of *Salmonella* typhimurium by polymerase chain reaction as a specific method of detection of *Salmonella*. *Mol Cell Probes*. 1992 Aug;6(4): 271-9.
- Ramtahal MA, Amoako DG, Akebe ALK, Somboro AM, Bester LA, Essack SY. A public health insight into *Salmonella* in poultry in Africa: A review of the past decade: 2010–2020. *Microb Drug Resist*. 2022 Jun;28(6):710-33.
- Samper-Cativuela C, Prieto ME, Collado S, De Frutos C, Branscum AJ, Saez JL, Alvarez J. Risk factors for *Salmonella* detection in commercial layer flocks in Spain. *Animals* (Basel). 2023 Oct 12;13(20):3181.
- Sanni AO, Onyango J, Usman A, Abdulkarim LO, Jonker A, Fasina FO. Risk factors for persistent infection of non-typhoidal *Salmonella* in poultry farms, North Central Nigeria. *Antibiotics* (Basel). 2022 Aug 18;11(8):1121.
- Smith SI, Seriki A, Ajayi A. Typhoidal and non-typhoidal *Salmonella* infections in Africa. *Eur J Clin Microbiol Infect Dis*. 2016 Dec;35(12):1913-22.
- Sonaiya EB, Oguntade EA, Adesina AA. Commercial poultry success stories in Nigeria: Drivers, challenges, and lessons [Internet]. FARA Research Report, Vol. 6, No. 11. Accra: Forum for Agricultural Research in Africa; 2022 [cited 2024 Feb 15]. 51 p. Available from: research4agrinovation.org/publications/page/3/.
- Uzochukwu BS, Onwujekwe OE. Socio-economic differences and health seeking behaviour for the diagnosis and treatment of malaria: A case study of four local government areas operating the Bamako initiative programme in south-east Nigeria. *Int J Equity Health*. 2004 Jun 17; 3(1):6.
- Van Hoorebeke S, Van Immerseel F, Haesebrouck F, Ducloux R, Dewulf J. The influence of the housing system on *Salmonella* infections in laying hens: A review. *Zoonoses Public Health*. 2011 Aug;58(5):304-11.
- Waghmare RN, Paturkar AM, Vaidya VM, Zende RJ, Dubal ZN, Dwivedi A, Gaikwad RV. Phenotypic and genotypic drug resistance profile of *Salmonella* serovars isolated from poultry farm and processing units located in and around Mumbai city, India. *Vet World*. 2018 Dec;11(12): 1682-8.
- Wang J, Vaddu S, Bhumanapalli S, Mishra A, Applegate T, Singh M, Thippareddi H. A systematic review and meta-analysis of the sources of *Salmonella* in poultry production (pre-harvest) and their relative contributions to the microbial risk of poultry meat. *Poult Sci*. 2023 May;102(5): 102566.
- Wegbom AI, Edet CK, Raimi O, Fagbamigbe AF, Kiri VA. Self-medication practices and associated factors in the prevention and/or treatment of COVID-19 virus: A population-based survey in Nigeria. *Front Public Health*. 2021 Jun 4;9:606801.
- WHO – World Health Organisation. *Salmonella* (non-typhoidal) [Internet]. Geneva: WHO; 2018 Dec [cited 2024 Feb 23]. Available from: [www.who.int/news-room/fact-sheets/detail/Salmonella-\(non-typhoidal\)](http://www.who.int/news-room/fact-sheets/detail/Salmonella-(non-typhoidal)).
- WHO – World Health Organisation. The burden of food-borne diseases in the WHO European Region [Internet]. Copenhagen: WHO Regional Office for Europe; 2017 Aug

<https://doi.org/10.17221/76/2025-VETMED>

[cited 2025 Mar 13]. 36 p. Available from: iris.who.int/items/01ecd244-af0b-42fd-9e83-e9045f66cbb7.

WHO – World Health Organisation. WHO estimates of the global burden of foodborne diseases: Foodborne Disease Burden Epidemiology Reference Group 2007–2015 [In-

ternet]. Geneva: WHO; 2015 Dec [cited 2022 Sep 21]. 265 p. Available from: apps.who.int/iris/bitstream/handle/10665/199350/9789241565165_eng.pdf.

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