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CHARACTERIZATION OF DOMINANT SALMONELLA STRAINS IN PEDIATRIC DIARRHOEA CASES IN KADUNA, KATSINA AND SOKOTO STATES, NIGERIA

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ABSTRACT

This research was aimed at characterizing Salmonella serotypes prevalent among children with diarrhoea within the study area. A total of 634 stool samples from children aged five years and younger, exhibiting diarrhea, were collected and analyzed for Salmonella infection using culture, biochemical methods, and serology. Salmonella serotypes were confirmed through sequence of 16S rRNA gene of the isolates. Among the research subjects, the general prevalence of Salmonella spp. was 4.1%. Children between the ages of 25 and 36 months had the highest prevalence (10.4%). The 16S rRNA gene of 18 isolates were sequenced, and while 7 (38.1%) were Salmonella enterica subspecies enterica serovar Typhimurium LT2, 11 (61.1%) were Salmonella enterica subspecies enterica serovar Typhi CT18. The percentage similarity from the BLAST results of all 16S sequences varied from 86% to 99%, with E-values below one. In the research area, Salmonella remains a primary and significant bacterial pathogen responsible for diarrhea in children; therefore, ensuring adequate access to potable water and vigilant surveillance of the incidence and transmission of diarrheal diseases can mitigate the disease burden in this population.

KEYWORDS: Paediatric Diarrhoea, Salmonella Typing, Sequence Analysis

INTRODUCTION

A major worldwide health issue still remains diarrhea diseases brought on by enteric infections. According to UNICEF, in 2021 the annual death due to diarrhoea among children, 5 years and below, globally, amounted to 444,000 (UNICEF, 2024). Particularly in Third World countries where there is a lack of basic sanitation, hygiene, and safe drinking water, it is a common cause of infant mortality (Omelonye *et al*, 2015). Diarrhea is still ranking third among all causes of death worldwide for children under five years old (WHO, 2024).

Reports from all around the world have linked different pathogens including *Cryptosporidium, Entamoeba histolytica, Salmonella* species, *Escherichia* coli, *Klebsiella* spp., *Enterobacter* spp., *Campylobacter jejuni*, and rotavirus with infantile diarrhea outbreaks (WHO, 2024), these pathogens are all endemic especially in every developing country. Although diarrhea is a preventable disease, it is still a primary factor of morbidity and death among children in Nigeria.

In Nigeria, the incidence of *Salmonella enterica* serovar Typhimurium is one of the most common serotypes in many countries, out of the more than 2,600 serotypes of the bacteria that have been identified (Issenhuth-Jeanjean *et al*., 2014; Takaya *et al*., 2019, Ehuwa, *et al*., 2021).

Salmonella-related issues have become much more prevalent in recent years, with a rise in the frequency and intensity of human cases of salmonellosis. Even antibiotic resistance rate among *Salmonella* spp. has been increasing, making it an issue of global concern (Jiu *et al.*, 2020).

Salmonella infection is an international public health risk, giving rise to a significant burden of disease in both developed and underdeveloped nations (Stanaway *et al.*, 2019, Kubra and Sayar, 2024). Although some developed nations have made substantial progress in reducing the rising cases of human salmonellosis, the situation remains different in developing regions of Africa and Southern Asia, where there is a lack of clean water and insufficient sanitation and hygiene standards (WHO, 2024).

Illnesses caused by *Salmonella* are on the rise, often leading to death in some instances. However, assessing the full extent of salmonellosis is challenging due to the limited number of studies, the absence of a coordinated epidemiological surveillance system, and insufficient laboratory facilities. This research was carried out to evaluate *Salmonella* serotypes prevalent among children within the study location.

MATERIALS AND METHODS

Study Area

Kaduna, Katsina and Sokoto states, within the Northwest geopolitical region of Nigeria were randomly selected for the study (see Fig. 1).

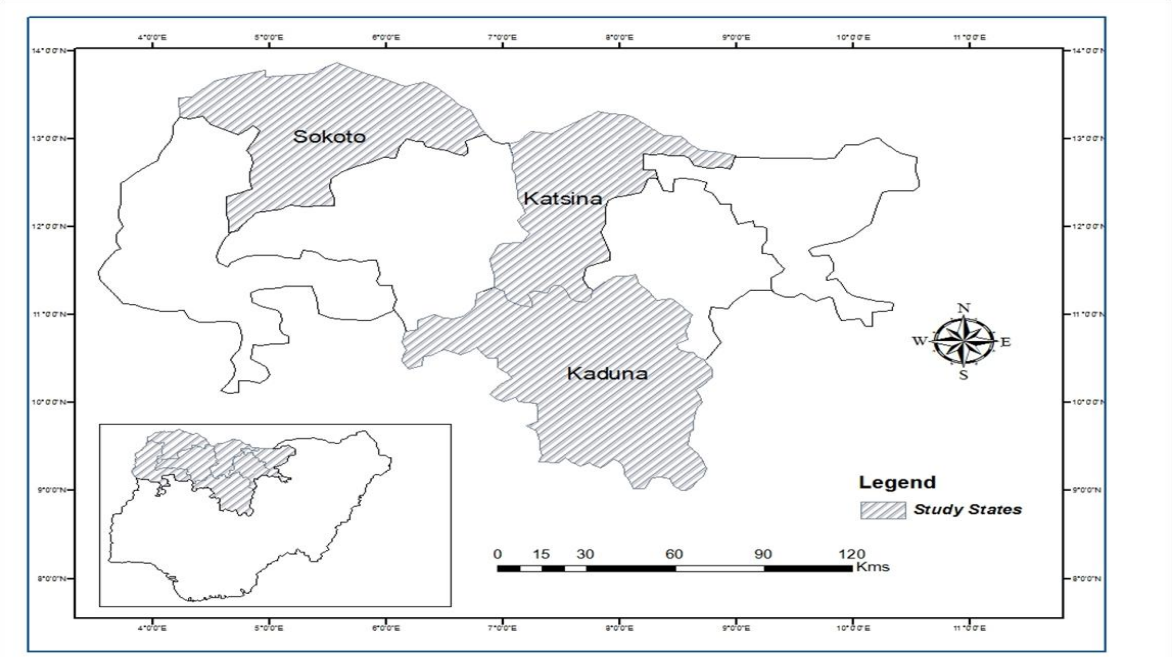


Fig. 1: Map of North Western Nigeria Showing Study States.

Study Population

The research was a hospital- and clinic-based cross-sectional design. The study subjects consisted of children aged 5 years or younger that were presented to hospitals or clinics with symptoms of diarrhoea or gastroenteritis.

Ethical Clearance

Ethical clearance was secured from the ethics committees from the respective State Ministries of Health involved in the study prior to commencement of the research.

Sample Collection

Approximately 5-10g of stool was collected using a plastic spoon and placed in a clearly labelled sterile universal bottle. Rectal swab was made in cases where it was not feasible to obtain stool sample, and placed in sterile physiological saline and the sample bottle was labelled appropriately. A total of 634 samples (344 from male and 290 from female children)

For further analysis, all samples were shipped in ice packs to the Bacteriology Laboratory, Department of Microbiology, Ahmadu Bello University, Zaria.

Bacteriological Examination of Faecal Samples

The faecal samples were first enriched in selenite F broth, and then sub-cultured into Salmonella-Shigella agar after incubation at 37^{o}C for 24hrs in each case. After further purification, the resulting isolates were subjected to biochemical characterization with the Microgen^{TM} GnA+B ID System for *Enterobacteriaceae*, according to the manufacturer's instructions. Serological confirmation of *Salmonella* isolates was carried out using polyvalent flagellar (H) and somatic (O) antisera (Microgen^{TM}).

Molecular Identification of Salmonella strains using 16S rRNA Sequencing

DNA from isolates was extracted using Zymo Research (ZR) Fungal/Bacterial DNA MiniPrep,™ following instructions from the manufacturer.

The DNA was subjected to the cocktail mix of 10µL, comprising 10× PCR buffer (1.0µL), 25mM $MgCl_2$ (1.0µL), 5pMol forward primer (0.5µL), 5pMol reverse primer (0.5µL), DMSO (1.0µL), 2.5Mm DNTPs (0.8µL), Taq 5u/ul (0.1µL), 10ng/µl DNA (2.0µL), H_2O (3.1µL), with the following forward and reverse primer sequences for the 16S rRNA. 27F: AGAGTTTGATCMTGGCTCAG, 1525R: AAGGAGGTGWTCCARCCGCA.

The PCR products were visualized on 1.5% agarose gel stained with GelRed. Selected amplicons were sequenced using the Sanger method. Sequences were analyzed using the National Center for Biotechnology Information BLAST database for species confirmation.

RESULTS

In terms of gender, out of the 344 males that were screened, 17(4.9%) were positive for *Salmonella* infection. While, out of 290 females screened, 9(3.1%), were positive for the infection (Table1). Among the study subjects, children between the ages of 25 and 36 months had the highest prevalence of isolation (10.4%), followed by those with the age bracket of 37-48 months (6.8%). The frequency declined to 4.4% for ages 13-24 months, 2.7% for ages 49-60 months and 0.5% for 0-12 months.

Table 1: Salmonella species prevalence as a function of research participants' age and sex.

Age group (months)	No. examined	No. (%) positive	No. Male	No. (%) positive	No. Female	No. (%) positive
0-12	222	4(1.8)	131	2(1.5)	91	2(2.2)
13-24	205	7(3.4)	102	5(4.9)	103	2(1.9)
25-36	96	10(10.4)	47	7(14.9)	49	3(6.1)
37-48	74	5(6.8)	45	3(6.7)	29	2(6.9)
49-60	37	0(0.0)	19	0(0.0)	18	0(0.0)
Total	634	26(4.1)	344	17(4.9)	290	9(3.1)

$\chi^2 = 15.876, df = 4, P = 0.003$

Antibiogram of *Salmonella* isolates indicated a high resistance (100%) to the β-lactam class of antibiotics and 56.8% to resistance to cefotaxime and tetracycline. There was no resistance observed for gentamicin and the fluoroquinolones showed great activity against the isolates (see table 2)

Table 2: Antibiotic resistance profile of *Salmonella* isolates from diarrheal stools

Antibiotic	Susceptibility (n =26)		
	S (%)	I (%)	R (%)
Ampicillin (10µg)	0(0.0)	0(0.0)	26(100)
Amoxycillin (10µg)	0(0.0)	0(0.0)	26(100)
Amoxicillin Clavulanic acid(30µg)	0(0.0)	0(0.0)	26(100)
Gentamicin (30µg)	26(100)	0(0.0)	0(0.0)
Sulphamethoxazole Trimethoprim (30µg)	19(73.1)	0(0.0)	7(26.9)

Chloramphenicol(30µg)	20(76.9)	2(7.7)	4(15.3)
Cefotaxime (10µg)	3(11.5)	9(34.6)	14(53.8)
Tetracycline(30µg)	12(46.2)	0(0.0)	14(53.8)
Ciprofloxacin(5µg)	24(92.4)	1(3.8)	1(3.8)
Nalidixic acid(30µg)	19(73.1)	4(15.4)	3(11.5)

Key: S- Susceptible, I- Intermediate, R- Resistance

Sequence analysis of 16S ribosomal RNA genes of isolates revealed two major strains viz; *Salmonella enterica* ser. Typhimurium and *Salmonella enterica* ser. Typhi. The latter being the dominant serotype. Percentage identity of isolates from results of the BLAST ranged from 86 to 99.

Table 3: Closest affiliations of 16S rRNA sequences obtained from isolates of Salmonella.

Subtype	No. detected	Prevalence (%)	Identity (%)	E-Value
Salmonella enterica ser. Typhimurium	7	39	86 - 99	0.0-2e-119
Salmonella enterica ser. Typhi	11	61	97 - 99	0.0–2e-107

DISCUSSION

In this study, a 4.1% prevalence of *Salmonella* species was found among 634 children within the study location. This underscores the diverse causes of children diarrhoea, including viruses, parasites, and other bacterial agents. These have been reported with varying prevalence rates globally.

Similar prevalence of *Salmonella* species in children were reported by researches carried out in Ethiopia (Mulatu *et al,* 2014; Tosisa *et al.,* 2020), the Gambia, Mali and Kenya Bangladesh (Kasumba *et al*., 2023). Prevalence rates observed from various studies including the present study (4.1%) vary significantly. This might be brought on by the stark variations in the study locations' environmental conditions, social conditions, and educational attainment among the populace. This data, however, reveals a lower prevalence than those from other locations of Nigeria, for instance Ogbu *et al.,* 2007 reported 11.3%, Duru *et al.,* 2014 (10%), and Ike and Damola, 2014 (10.7%). The discrepancy could be caused by variations in the study's design, the patients' choices, the environments, and the behavioural patterns of the local population.

According to the study's findings, children between the ages of 13–24 months and 25–36 months had the highest prevalence of Salmonella species. This may result from the combined effects of dwindling maternally acquired immunity, the absence of a well-developed active immunity, food contamination, and the infant's early exposure to human or animal excrement.

A child's growth and development are likewise at a very active stage during this age range. It can also be stated to coincide with the time when children's exposure to environmental infections rises sharply (Duru *et al.,* 2014), usually as a result of their lack of knowledge about the fundamentals of aseptic or sanitary procedures (Sule *et al.,* 2011).

Children who are exposed to these factors, along with *Salmonella'*s high virulence and low infectious dosage, are more susceptible to infection. Infection rate

declined from children aged 37–48 months (19.2%) and 49–60 months (3.8%), probably an indication of improvement in dietary habits and immune system. One possible explanation for the low frequency in the 0–12 months age group is breastfeeding. They are shielded from infectious agents by antibodies found in breast milk.

The resistance to β-lactam antibiotics in this study is particularly alarming, since they are commonly employed for treatment of various infections in the study area. All the *Salmonella* strains exhibited differing percentages of susceptibility to Nalidixic acid (72.4%), Ciprofloxacin (89.7%), and Sulphamethoxazole Trimethoprim (72.4%). This indicates that these chemotherapeutic drugs are relatively successful in treating diarrhea caused by these infections. Ciprofloxacin use in young children carries serious risks because adverse symptoms such as irregular or uneven heartbeat, convulsions, face, lips, tongue, mouth, or throat swelling, difficulty breathing, and fainting or uncontrollably shaking might result.

Similarly, Pitti *et al.* (2023), reported that 85.1% *Salmonella* isolates in their study were resistant to at least one class of antibiotics and 79.2% were resistant to ampicillin.

Since most rural and urban people lack easy access to the better and more effective antibiotics, such ciprofloxacin, resistance, especially to frequently available antibiotics, poses serious health risks. The high susceptibility of *Salmonella* to ciprofloxacin as shown in this study is probably because the antibiotic is very expensive and not readily available and therefore are less abused.

The *Salmonella* isolates in this investigation were 100% susceptible to the aminoglycoside gentamicin; nonetheless, it has been noted that *Shigella* and *Salmonella* species may look actively susceptible to aminoglycosides in vitro, they are not necessarily clinically effective, and therefore should not be considered therapeutic (CLSI, 2021). Resistance of *Salmonella* spp. to various antibiotics has been demonstrated in previous studies, and has been increasing. Duru *et al.,* (2014), Moses *et al.,* (2014) and Jiu *et al.,* (2020), have previously reported a high resistance by *Salmonella* to beta-lactam antibiotics.

Out of the 18 randomly chosen *Salmonella* isolates, 11 were identified as *Salmonella enterica* serovar Typhi and 7 as *Salmonella enterica* serovar Typhimurium, according to the basic local alignment search tool (BLAST) analysis of 16S rRNA to confirm *Salmonella* serovars dominant in the study population.

Since *Salmonella* Typhi is essentially a human pathogen, its prevalence in this study may be attributable to inadequate sanitation and poor hygiene among caregivers, which promote the pathogen's transmission from adult carriers, fecaly contaminated water and food. Epidemiologically, *S.* enteritidis has been predominantly reported in the EU, however studies in Italy showed higher prevalence of *S.* ser. Typhimurium (EFSA and ECDC, 2021; Pitti *et al.,* 2023)

Interventions aimed at reducing the menace of infectious diseases and Salmonellosis includes; the establishment of Nigeria Centre for Disease Control (NCDC) in December 2018. This establishment is a government intervention focused on creating and maintaining a network of specialist

reference laboratories, efficient mechanisms for coordinating surveillance, and strategic management of diseases with significant public health implications (Akinyemi *et al.*, 2021). Analyses for Nigeria indicate that a yearly efficient One Health initiative that targets the management, surveillance, and control of non-typhoidal *Salmonellosis* in poultry, along with administration of antibiotics in humans, will require at least 4,835 technical officers and 3,700 non-technical staff (n = 8,535). Over 2.2 million work hours and a total investment of US$ 53,854,660.87 will be required for this effort (Sanni *et al.*, 2024).

Probiotic bacteria and Direct Fed Microbials (DFMs) are gaining considerable endorsement as interventions because of prevailing concerns regarding resistance to antibiotic, and the rise of organic farming as a substantial factor in both local and international markets. (Tellez *et al*., 2012; Nair *et al.,* 2018). *Propionibacterium freudenreichii*, a dairy probiotic microbe, has demonstrated efficacy against *Salmonella* spp. (Nair *et al.*, 2018).

Additionally, the use of natural chemicals against foodborne pathogens as an alternative to antibiotics is gaining traction. Volatile aromatic compounds, known as essential oils, derived from various plant parts, have been shown to be effective both in vitro and in vivo against foodborne pathogens, including *Salmonella* (Surendran *et al.*, 2016; Kollanoor-Johny *et al.*, 2017).

According to Nair *et al.* (2018), prebiotics are non-digestible carbohydrate substrates that, when added to the diet, specifically encourage the growth of the majority of probiotic or beneficial bacteria. The formation of short-chain fatty acids and the proliferation of intestinal probiotic bacteria like *Lactobacillus* and *Bifidobacterium* are the main effects of these fermentable carbohydrates in the lower intestine.

Plans have been made to restrict or outlaw the use of some antimicrobials in an effort to stop the spread of antimicrobial resistance and to improve public health and food safety. Limiting the inappropriate use of antibiotics and enhancing cleanliness standards in healthcare facilities and the food chain may contribute to stopping the spread of resistant microbes, which can have multiple contributing factors, and limit the development of antimicrobial resistance (AMR).

CONCLUSION

The research findings indicate that Salmonella continues to be a significant bacterial pathogen causing diarrhea in children within the study area. The study's findings regarding antibiotic susceptibility reveal a significant percentage of resistance among the isolates, particularly against the β-lactam class of antibiotics, which renders them totally unreliable for treating Salmonella infections. Molecular typing of the isolates using 16S rRNA gene sequencing revealed two main strains of *Salmonella* within the study area, predominantly *Salmonella enterica* ser. Typhi and *Salmonella enterica* ser. Typhimurium.

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Declarations

Ethics approval and consent to participate

The study was conducted in full accordance with the ethical principles outlined in the **Declaration of Helsinki** (as revised in 2013). Prior to commencement, the Ethical Review Committee of Katsina State Ministry of Health, Katsina, Nigeria, reviewed and approved the study protocol (MOH/ADM/SUB/1152/1/813). All clinical samples were collected with due respect for patient rights, and informed consent was obtained from legal guardians of all participants. Patient confidentiality and anonymity were strictly maintained throughout the study. No procedures were performed that posed additional risk to the patients beyond routine clinical sampling.

REFERENCES

UNICEF. Diarrhoea. *UNICEF Data: Monitoring the situation of children and women.* 2024, Diarrhoea - UNICEF DATA

WHO. Diarrhoeal Disease. 2024, WHO Fact sheet. http://www.who.int/news-room/fact-sheets/detail/diarrhoeal-disease.

Omelonye, K.E., Okolo, C.A., Nwibo, D.D., Chukwuka, C.O., Nwibo, M.I and Ubachukwu, P.O. Prevalence and management of diarrhoea among children in Nsukka, Nigeria. *Ani. Res. Int.* 2015, 12(1):2107–2113.

Issenhuth-Jeanjean, S., Roggentin, P., Mikoleit, M., Guibourdenche, M., Pinna, E. D., Nair, S., et al. Supplement 2008–2010 (no. 48) to the White– Kauffmann–Le Minor scheme. *Res. Microbiol.* 2014, 165: 526–530. doi: 10.1016/j. resmic.2014.07.004.

Takaya, A., Yamamoto, T., and Tokoyoda, K. Humoral immunity vs. Salmonella. *Front. Immunol*. 2019, 10:3155. doi: 10.3389/fimmu.2019. 03155.

Simpson, K.M.J., Hill-Cawthorne, G.A., Ward, M.P. and Mor, S.M. Diversity of *Salmonella* serotypes from humans, food, domestic animals and wildlife in New South Wales, Australia. *BMC Infectious Diseases*, 2018, 18:623

Ehuwa, O., Jaiswal, A. K., & Jaiswal, S. *Salmonella*, Food Safety and Food Handling Practices. *Foods (Basel, Switzerland)*, 2021, 10(5), 907.

Jiu, Y., Meng, X., Hong, X., Huang, Q., Wang, C., & Chen, Z. Prevalence and characterization of Salmonella in three typical commercial pig abattoirs in Wuhan, China, 2020.

Kübra Dindar Demiray, E., & Sayar, B. Salmonella Disease with a Health Management Perspective. *Intech. Open*, 2024. doi:10.5772/intechopen.1005026.

Foodborne Pathogens and Disease, 2019, 17(10), 620–627.

Stanaway, J. D., Parisi, A., Sarkar, K., Blacker, B. F., Reiner, R. C., Hay, S. I., *et al*. The global burden of non-typhoidal Salmonella invasive disease: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet Infect. Dis*. 2019, 19:1312–1324.

Ajmera A, Shabbir N. Salmonella. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024.

Mulatu, G., Beyene, G. and Zeynudin, A. Prevalence of Shigella, Salmonella and Campylobacter Species and Their Susceptibility Patters Among Under Five Children with Diarrhea in Hawassa Town, South Ethiopia,

Ethiop J Health Sci., 2014, 24(2):101-108.

Tosisa, W., Mihret, A., Ararsa, A., Eguale, T., & Abebe, T. Prevalence and antimicrobial susceptibility of Salmonella and Shigella species isolated from diarrheic children in Ambo town. *BMC pediatrics*, 2020, 20(1): 91.

Kasumba, I.N., Powell, H., Omore, R., Hossain, M.J. Sow, S.O., Ochieng, J.B., *et al*. Prevalence of *Salmonella* in Stool During the Vaccine Impact on Diarrhea in Africa (VIDA) Study, 2015–2018, *Clinical Infectious Diseases*, 2023, 76(1): S87-S96.

Ogbu, O., Agumadu, N., Uneke, C. and Amadi, E. Aetiology of Acute Infantile Diarrhoea in the south-Eastern Nigeria: An Assessment of Microbiological and Antibiotic Sensitivity Profile. *The Internet Journal of Third World Medicine*. 2007, 7(1).

Duru E. E., Agbagwa O. E.,and Umoren F. E. Bacterial Agents Associated with Infantile Diarrhoea and their Antibiotics Susceptibility Pattern in Port Harcourt, South-South, Nigeria. *Journal of Medical Sciences and Public Health*, 2014, 3(1): 1-12.

Ike, A.A., Damola, A.B. Prevalence of enteric pathogens among patients with gastrointestinal presentations in the Lagos University Teaching Hospital (LUTH), Idi Araba Lagos Nigeria. *IOSR Journal of Pharmacy and Biological Sciences.* 2014, 9(5): 12-17.

Sule, E.I., Aliyu A.M and Abdulaziz, B.M. Isolation of Diarrhoeagenic Bacteria in Children Attending Some Selected Hospitals Within Kaduna Metropolis, Kaduna State, Nigeria. *Continental Journal of Applied Sciences*, 2011, 6 (1): 1 - 6.

Pitti, M.; Garcia-Vozmediano, A.; Tramuta, C.; CeRTiS Clinical Laboratories Group; Maurella, C.; Decastelli, L. Monitoring of Antimicrobial Resistance of Salmonella Serotypes Isolated from Humans in Northwest Italy, 2012–2021. *Pathogens*, 2023, 12:89.

Clinical and Laboratory Standards Institute (CLSI). *Performance Standards for Antimicrobial Susceptibility Testing*. 31st ed. CLSI supplement (ISBN 978-1-68440-105-5 [Electronic]). Clinical and Laboratory Standards Institute, USA, 2021.

Moses, I.B., Oluduro, A.O., Isawumi, A., Ariyo, A.B., Fashina, C.D., Ajayi, A.O. Antibiotic resistance and Molecular characterization of *Salmonella* in diarrhoeal patients' faeces in south-western Nigeria. *Journal of Biology, Agriculture and Healthcare*, 2014, 4(24): 152-161.

EFSA and ECDC (European Food Safety Authority and European Centre for Disease Prevention and Control). The European Union One Health 2020 Zoonosis Report. *EFSA J.*, 2021, 19: 6971.

Akinyemi K.O., Ajoseh S.O. and Fakorede C.O. A systemic review of literatures on human *Salmonella enterica* serovars in Nigeria (1999-2018). *J Infect Dev Ctries*., 2021, 15(9):1222-1235.

Sanni, A. O., Jibril, A. H., Fasanmi, O. G., Adebowale, O. O., Jambalang, A. R., Shittu, A., Fasina, F. O. Non-typhoidal *Salmonella* in Nigeria: do outcomes of 'multisectoral' surveillance, treatment and control justify the intervention costs? *International Journal of*

Veterinary Science and Medicine, 2024, 12(1): 48–59.

Tellez, G.; Pixley, C.;Wolfenden, R.E.; Layton, S.L.; Hargis, B.M. Probiotics/direct fed microbials for *Salmonella* control in poultry. *Food Res. Int*., 2012, 45: 628–633.

Nair, D.V.T.; Venkitanarayanan K. and Kollanoor-Johny, A. Antibiotic-Resistant Salmonella in the Food Supply and the Potential Role of Antibiotic Alternatives for Control. *Foods*, 2018, 7:167.

Surendran Nair, M.; Lau, P.; Belskie, K.; Fancher, S.; Chen, C.-H.; Karumathil, D.P.; Yin, H.-B.; Liu, Y.; Ma, F.; Upadhyaya, I.; *et al***.** Potentiating the heat inactivation of Escherichia coli O157:H7 in ground beef patties by natural antimicrobials. *Front. Microbiol.*, 2018, 7: 15.

Kollanoor-Johny, A.; Frye, J.G.; Donoghue, A.; Donoghue, D.J.; Porwollik, S.; McClelland, M.; Venkitanarayanan, K**.** Gene Expression Response of Salmonella enterica serotype Enteritidis Phage Type 8 to subinhibitory concentrations of the plant-derived compounds trans-cinnamaldehyde and eugenol. *Front. Microbiol*., 2017, 8, 1–10.