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Epidemiology of Animal and Human *Campylobacter* Species Infections in Nigeria: A Retrospective Insight and the Need for One Health Approach in the Prevention and Control

Nijerya'da Hayvan ve İnsan Campylobacter Türleri Enfeksiyonlarının Epidemiyolojisi: Retrospektif Bir Bakış ve Önleme ve Kontrolde Tek Sağlık Yaklaşımına Olan İhtiyaç

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ABSTRACT

Campylobacter infection is zoonotic and has remained a global economic and public health concern. The bacteria cause gastroenteritis and other debilitating health and economic problems in both animals and humans. Epidemiological factors and risk practices aiding the acquisition and dissemination of the infection still subsist in developing countries, particularly Nigeria, but epidemiological information on the distribution and control of the infection is sparse. Taking cognizance of the significance of epidemiological data, this study systematically reviewed 53 eligible articles on the prevalence and antimicrobial resistance profile of *Campylobacter* isolates from animals, food matrices, and humans in Nigeria from 1981 to 2022. The 53 articles have a pooled sample population of 9329, 3529, 571, and 5523 from animals, food matrices, water, and humans, respectively. *C. jejuni* and *C. coli* were the most reported species with prevalence range: 5.3%-60.7%, 3.5%-92.7%, 14.3%-27.7%, 8.8%-68.8%, 4.8%-96%, 0.5%-43.8%, and 7%-70% in poultry, other food-producing animals, companion animal, water, food of animal origin, children <5 years old, and other individuals at risk, respectively. A pooled prevalence of 26.8%, 23.1%, 20.7%, 34.8%, 53.7%, 12.7%, and 25.4% in the same order was calculated. Of the 53 articles reviewed, molecular diagnostics tools were employed in 11 (21%) while multidrug resistance was reported in 15 (28%). Intensification of food animal production, use of protective wares by animal and meat handlers, adequate cooking of foods of animal origin, prudent use of antibiotics in animal agriculture, and a coordinated One Health approach to the control of campylobacteriosis has become pertinent in Nigeria.

Keywords: Animal, *Campylobacter*, epidemiology, humans, Nigeria

ÖZ

Campylobacter enfeksiyonu zoonotiktir ve küresel bir ekonomik ve halk sağlığı sorunudur. Bakteriler hem hayvanlarda hem de insanlarda gastroenterit ve diğer sağlığı zayıflatıcı ve ekonomik sorunlara neden olurlar. Enfeksiyonun edinilmesi ve yayılmasına yardımcı olan epidemiyolojik faktörler ve risk uygulamaları gelişmekte olan ülkelerde özellikle Nijerya'da hala varlığını sürdürmektedir, ancak enfeksiyonun dağılımı ve kontrolü hakkında epidemiyolojik bilgi yetersizdir. Epidemiyolojik verilerin önemini göz önünde bulundurarak, bu çalışma 1981-2022 yılları arasında Nijerya'da hayvanlardan, gıda matrislerinden ve insanlardan Campylobacter izolatlarının yaygınlığı ve antimikrobiyal direnç profilleri üzerine 53 uygun makaleyi sistematik olarak incelemiştir. 53 makale, sırasıyla hayvanlardan, gıda matrislerinden, sudan ve insanlardan 9329, 3529, 571 ve 5523 örnekleme popülasyonuna sahiptir. C. jejuni ve C. coli en yaygın rapor edilen türler olup, prevalans aralığı sırasıyla; tavuklarda %5.3-60.7, diğer gıda üretiminde kullanılan hayvanlarda %3.5-92.7, evcil hayvanlarda %14.3-27.7, su kaynaklarında %8.8-68.8, hayvansal kaynaklı gıdalarda %4.8-96, 5 yaşın altındaki çocuklarda %0.5-43.8 ve diğer risk altındaki bireylerde %7-70'tir. Aynı sırayla hesaplanan birleşik prevalans sırasıyla %26.8, %23.1, %20.7, %34.8, %53.7, %12.7 ve %25.4'tür. İncelenen 53 makalenin 11'inde (%21) moleküler tanı araçları kullanılırken, çoklu ilaç direnci 15'inde (%28) rapor edilmiştir. Nijerya'da, gıda hayvanı üretiminin yoğunlaştırılması, hayvan ve et işleyicileri tarafından koruyucu ekipmanların kullanımı, hayvansal kökenli gıdaların yeterli pişirilmesi, hayvan tarımında antibiyotiklerin özenli kullanımı ve kamfilobakteriyozun kontrolünde koordineli bir Tek Sağlık yaklaşımını önemli hale getirmektedir.

Anahtar Kelimeler: Hayvan, Campylobacter, epidemiyoloji, insanlar, Nijerya

INTRODUCTION

Campylobacter species are the etiologic agent of campylobacteriosis in both animals and humans. Most *Campylobacter* species, particularly the thermophilic species, are zoonotic and require a microaerophilic culture environment for optimal growth. Generally, *Campylobacter* species are Gram-negative bacteria. The organisms are usually spiral, comma, or rod-shaped and colonize the gastrointestinal tract of most warm-blooded animals, food-producing animals (especially poultry), pets, and humans.[1] *Campylobacter* infections may be asymptomatic, depending on the immune status of the host and the organisms can be discharged into the environments through the feces of infected hosts.[2] Different animal species especially poultry have been reported as reservoirs of *Campylobacter* species for human infection.[3] Foods of animal origin, including processed chicken, other meat products, milk (especially unpasteurized milk), cheese, and untreated water could be major sources of *Campylobacter* infections. Approximately, 70%-80% of cases of campylobacteriosis have been attributed to poultry sources either at the farm level and processing units or due to contact with contaminated carcasses or ingestion of contaminated meat products.[4] The ability of the organisms to survive over time, even in freezing conditions, and remain viable but not culturable may have contributed to the spread of the infection via contaminated food products.[2]

Campylobacter species are of immense public health importance due to their ability to cause gastroenteritis and other health problems in humans; especially among risk groups (immunologically naive/compromised and or occupationally exposed individuals). These include children (<5 years old), the elderly, pregnant women, livestock farmers, butchers/animal handlers, and HIV/TB patients.[1,5] The infection is worldwide in distribution but high prevalence has been reported in animals and humans in many developing countries including Nigeria.[1] The socio-economic burden and intervention cost associated with campylobacteriosis and other zoonotic diseases in Nigeria have been estimated at 8.8% and 10.9%, respectively.[6] The actual impact in the developed countries has been estimated at 27 million euros per year unlike in the developing countries where the actual impact of the infection has remain indefinable either as a result of deficiency in awareness or complexity in the diagnosis within sensate and paradoxically applied isolation methods.[7]

In Nigeria, the risk practices aiding *Campylobacter* infection are common. Almost every household is involved in subsistent poultry or livestock production for income generation or provision of animal protein.[8] Furthermore, poor biosecurity, environmental hygienic practices, and contaminated water sources, both at the farm and at the abattoir levels where food-producing animals are reared or processed without good hygiene practices have also contributed to the spread of *Campylobacter* organism in developing countries.[4,9] Lack of awareness of the public health implication of *Campylobacter* infection, inaccurate diagnosis, and wrong use of antibiotics in animals including self-medication in the management of gastroenteritis cases in humans may have led to the increase in the development of antimicrobial resistant strains and transfer of resistant genes.[10] In view of the public health and economic impacts of *Campylobacter* infection, there is a need for a retrospective insight on the prevalence and antimicrobial resistance status of the bacteria from both animal and human sources in Nigeria in order to proffer an evidence-based One Health prevention and control strategy.

MATERIALS AND METHODS

Literature Search

A systematic search and review for original articles and research work carried out in Nigeria and published between 1981 and 2022 were accessed using "Pub Med," "Google Scholar," "Research gate," and "African Journal Online." The databases were originally searched for the availability of identical reviews to avoid replication of any earlier research. The systematic search of these databases was performed using the search terms including the prevalence of *Campylobacter* species infections in food-producing animals, companion animals, food of animal origin, water and humans in Nigeria, and resistance to antibiotics. Articles were eligible for review when they: (i) contained data from any geopolitical region in Nigeria and (ii) were published between 1981 and 2022.

Data Extraction

Data such as the first author, year of publication, state, and region of the country in Nigeria where the study was conducted, type of animals (pet or food-producing animals) sampled, description of the sample population, type of samples collected and sample size, *Campylobacter* species prevalence, laboratory diagnostic methods employed and antimicrobials susceptibility testing were collated in the selected articles. Articles for which the sample size or prevalence was not shown or which used archived *Campylobacter* cultures were excluded (Figure 1).

RESULTS

Out of the 6 geopolitical zones in the country, reports on *Campylobacter* infections were found in 4 namely; southeast, southwest, northwest, and north central while no report was found in northeast and south-south parts of the country (Figure 2).

It was revealed that 50.9% (27/53) of studies on *Campylobacter* infection in Nigeria were in animals, followed by 26.4% (14/53) in humans while the food of animal origin and water were at 17.0% (9/53) and 5.7% (3/53), respectively. Out of a pooled population of 9329, 3529, 571, and 5523 samples from animals, food of animal origin, water, and humans, respectively, in the selected articles, *Campylobacter* species infection prevalence range of 5.3-60.7%, 3.5-92.7%, 14.3-27.7%, 8.8-68.8%, 4.8-96%, 0.5-43.8%, and 7-70%

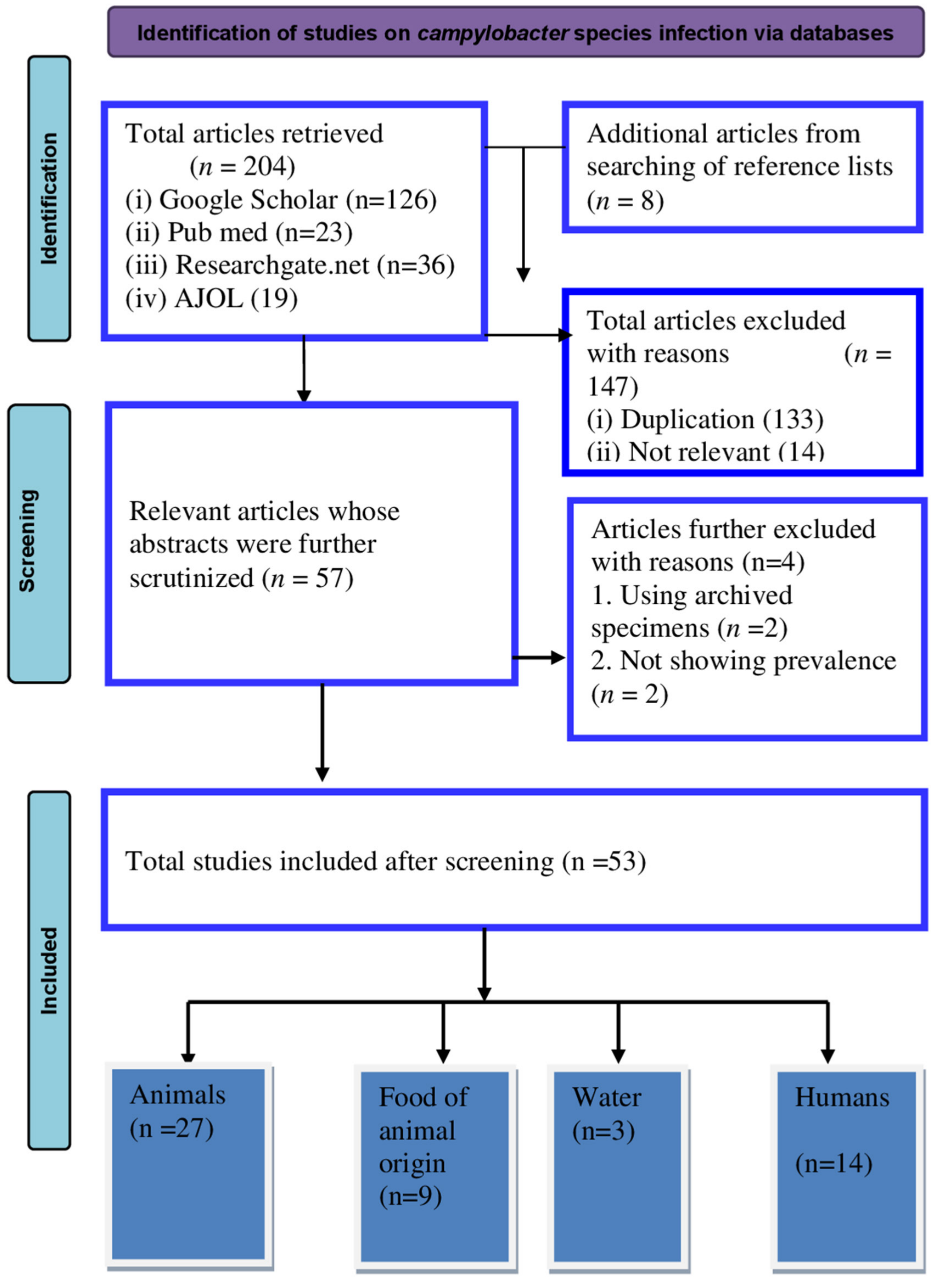

Figure 1. Flow diagram summarizing the process of literature search and article selection.

were in poultry, other food-producing animals, companion animal, water, food of animal origin, children, and other risk groups of individuals, respectively, with a pooled prevalence of 26.8%, 23.1%, 20.7%, 34.8%, 53.7%, 12.7%, and 25.4% in the same order.

In poultry, a pooled prevalence of 19.2%, 24.5%, 25.0%, and 38.5% were in the southeast, southwest, northwest, and north central states of the country, respectively, while 12.6%, 33.6%, and 23.3% were in southwest, northwest, and north central zones, respectively, for other food-producing animals. In pets, 20%, 23%, and 19.5% were the pooled prevalence in the southwest, northwest, and north central, respectively. Furthermore, a pooled prevalence of 8.8% and 60.7% were for water in the southeast and northwest of the country, respectively. In foods of animal origin, a pooled prevalence of 23.3%, 96%, 27.5%, and 68% was revealed in southeast, southwest, northwest, and north central zones of the country, respectively (Figure 3).

In humans, 8.3%, 14.4%, and 15.3% were the pooled prevalence in children in southeast, southwest, and north-west regions of the country, respectively, while 18.5%, 27.7%, 45.0%, and 10.2% were the rates for other individuals at risk in the southeast, southwest, northwest, and north-central region of the country, respectively (Figure 3). *C. jejuni* and *C. coli* were the most commonly reported species in food-producing animals, foods of animal origin, and humans while *C. upsaliensis* and *C. hyointestinalis* were the most frequently reported species in pets and water, respectively. Multidrug resistant (MDR) strains of *Campylobacter* species and 0%-100% resistance to commonly used antimicrobials in both human and animal sources were reported.

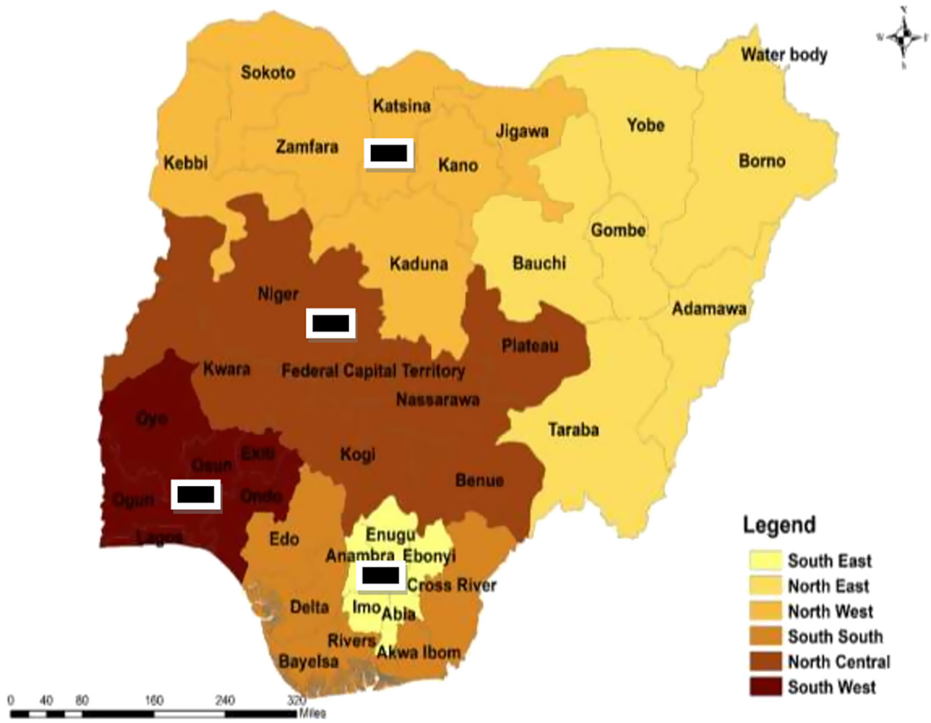

Figure 2. Map of Nigeria showing the constituent 6 geopolitical zones and black rectangles indicating zones where there are published data on *Campylobacter* infections.

Reports in Animals and Food of Animal Origin from Southeast, Nigeria

A prevalence of 37% had been reported in birds in Nsukka with *C. jejuni, C. coli,* and *C. lari* accounting for 64%, 23%, and 13% of the isolates, respectively.[11] The isolates were resistant at 84%, 61%, 58%, 43%, 43%, 9%, 5%, 5%, and 0% for cephalothin, cephalexin, ampicillin, streptomycin, cotrimoxazole, perfloxacin, ofloxacin, ciprofloxacin, and gentamicin, respectively, and 75% MDR.[11] The reports of 18.9% and 19.4% prevalence in poultry further prove a significant reduction in the infection rate in Nsukka, Enugu State, Nigeria over a decade.[3,8] Moreover, a lower prevalence of 14.2% has equally been reported in processed chicken with *C. jejuni* and *C. coli* accounting for 27.6% and 72.4% of the isolates, respectively, in the same study area.[4] In Imo State, Nigeria, studies have reported different prevalence rates ranging from 43-56% and 16-22% in beef and chicken, respectively, as well as 13.25%, 12.75%, 12.75%, and 12.25% in ready-to-eat meat, turkey meat, chicken meat, and beef, respectively.[12,13] A 3-year study in Orlu, Imo State, Nigeria has also revealed the prevalence of *Campylobacter* species at 22.6%, 12.7%, and 8.8% in beef, chicken, and water, respectively.[14] It was further reported that ceftriaxone inhibited the highest number of the isolates while tetracycline inhibited the least number due to their over-usage in the study area[14] (Table 1).

Reports in Humans from Southeast, Nigeria

A report of 8.3% prevalence has been reported in humans in Enugu State, Nigeria of which 93% of the isolates were *C. jejuni*.[15] A 3-year study in Orlu, Imo State, Nigeria has also reported

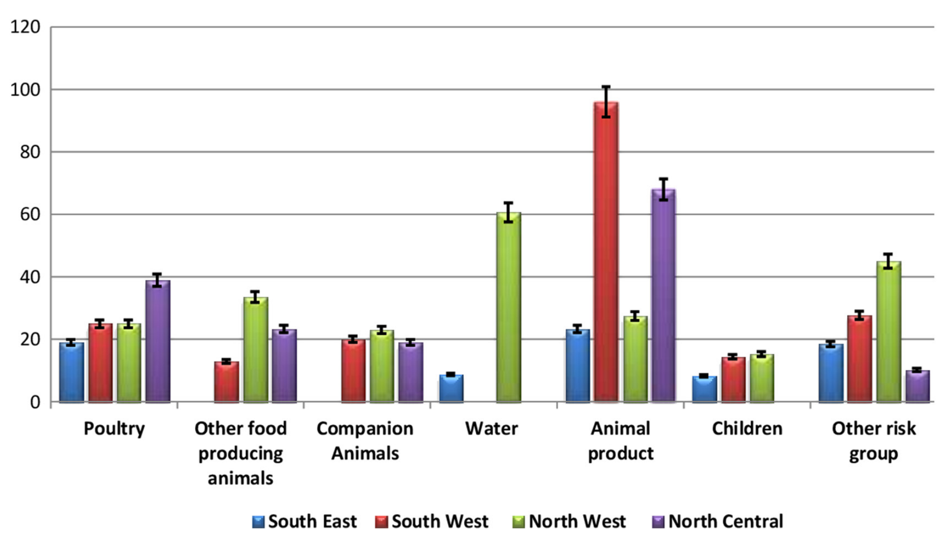

Figure 3. Prevalence and distribution of *Campylobacter* species infections in animals, food matrix, and humans in Nigeria.

Table 1. Prevalence and Distribution of *Campylobacter* Species Infection in Southeast, Nigeria

S. No.	Sources	Prevalence in %	Species	Sample Size	Method of Diagnosis	State	Reference
1	Poultry	19.4	Not indicated	640 fecal	Culture	Enugu	[8]
2	Poultry	18.9	Not indicated	316 fecal	Culture and biochemical test	Enugu	[3]
3	Layers	37	*C. jejuni*, *C. coli*, and *C. lari* at 64%, 23%, and 13%, respectively	275 fecal	Culture and biochemical tests	Enugu	[11]
4	Beef and chicken	22.6 and 12.7	Not indicated	620 beef and 553 chicken	Culture and antibiotics sensitivity	Imo	[14]
5	Beef and chicken	43-56	Not indicated	600 beef and chicken	Culture and biochemical test	Imo	[12]
6	Chicken meat, Turkey, beef, and ready-to-eat meat	12.75,12.75, 12.25, and 13.25	*C. jejuni*	400 raw meat	Culture and API campy kits	Imo	[13]
7	Poultry carcass surfaces	14.2	*C. jejuni* 27.6% and *C. coli* 72.4%	204 swabs	Phenotypic and PCR	Enugu	[4]
8	Water	8.8		465 water	Culture and antibiotics sensitivity	Imo state	[14]
9	Diarrheic children	8.3	*C. jejuni* 93%	514 stool	Microscopy and culture	Enugu	[15]
10	Humans	18.5		988 stool	Culture and antibiotics sensitivity	Imo state	[14]

campylobacteriosis as a re-emerging infectious disease of public health importance with 18.5% prevalence in humans[14] (Table 1).

Reports in Animals and Food of Animal Origin from Southwest, Nigeria

A report of 5.3% prevalence had been recorded in Lagos State, Nigeria in a pilot study involving 150 poultry of which 100% of the isolates were resistant to nalidixic acid, chloramphenicol, cloxacillin, and streptomycin while 87.5% and 62.5% were susceptible to amoxicillin/clavulanic acid and erythromycin, respectively.[16] Furthermore, 30% strains of *Campylobacter* isolates from poultry fecal droppings had been characterized as 66.7%, 20.0%, and 6.7% *C. coli* biotype1, *C. jejuni* biotype 1, and biotype II of the 2 species, respectively.[17] In Oyo State, 20.4% prevalence of MDR *C. coli* had been reported in cattle and chicken with 34%, 12%, and 10% in rectal, gall balder, and cloaca samples, respectively.[18] A study has revealed a 96% prevalence for *Campylobacter* species in chicken at Ibadan, Oyo State, and the isolates were resistant to nalidixic acid, gentamicin, and erythromycin at 100% and to enrofloxacin, chloramphenicol, streptomycin, and tetracycline at 38.0%, 46.0%, 50.0%, and 58.0%, respectively.[19] The use of modified charcoal cefoperazone deoxycholate agar m in comparison with Preston broth pre-enrichment and subsequent subculturing on Mueller Hinton agar with growth supplements, has revealed 16.8% and 26% prevalence, respectively, for *Campylobacter* species in layer birds in Ogun State, South Western Nigeria.[20] The isolates from the 2 media were confirmed as *Campylobacter* species at zero and 22% in that same order with the use of PCR.[20] The PCR-positive isolates were 90%, 10%, and 0% *C. coli*, other *Campylobacter* spp., *and C. jejuni*, respectively. The isolates were resistant to tetracycline, ciprofloxacin, erythromycin, spectinomycin, and tylosin at 100%, 90%, 60%, 90%, and 80%, respectively.[20] Furthermore, a study in the western part of Nigeria reported the prevalence of *Campylobacter* spp. at 15.4%, 15%, 20%, 6.25%, 12.5%, and 27.5% in poultry, cattle, dogs, sheep, goats, and pigs, respectively, with the isolates as *C. jejuni, C. coli,* and *C. fecalis* at 79.9%, 12.7%, and 7.2% prevalence, respectively.[21] A study in Lagos, has reported a prevalence of 14% with 7.1%, 25%, 7.1%, and 60.7% in pig, chicken, sheep, and guinea fowl, respectively.[22] The isolates were positive for *C. coli* biotype II, *C. coli* biotype I, and *C. jejuni* at 17%, 100% and 1%, respectively[22] (Table 2).

Reports in Humans from Southwest, Nigeria

A prevalence of 0.5% has been reported in children with diarrhea, aged between 0 and 36 months in Osogbo, Osun State, Nigeria.[23] A case–control study has also reported a prevalence of 19.1% among diarrheic children in Ile-Ife, Nigeria with *C. coli* accounting for 53.3% of the isolates which were all susceptible to erythromycin but without evidence of beta-lactamase production.[24] Furthermore, in another study in Osun State, 25 out of 57 *Campylobacter* strains from 815 diarrheic stool samples were identified as 72% *C. jejuni* and 28% *C. coli*.[25] The *C. jejuni* was classified into biotypes I (44.4%) and II (55.6%) while all the *C. coli* were of biotype I.[25] A study has reported the prevalence of 68% for *Campylobacter* spp among HIV patients in Ibadan, Oyo State, Nigeria with higher occurrence in male than the female HIV patients.[26] From the same report, *C. upsaliensis* (26.7%) was the most prevalent species followed by *C. jejuni* (25.0%), *C. lari* (19.2%), *C. coli* (16.7%), and *C. fetus* (12.5%). The isolates were sensitive to amikacin, amoxicillin/clavulanic acid, ciprofloxacin, ertapenem, nalidixic acid, and aztreonam at 92.5%, 70.0%, 92.5%, 90.0%, 69.2%, and 55.0%, respectively, while resistance to gentamycin, chloramphenicol, cefixime, and cephalothin was at 19.2%, 26.7%, 31.7%, and 39.2% in the same order.[26] A study has also reported the prevalence of *Campylobacter* species at 16.5% among diarrheic children at health centers in Lagos, Nigeria with *C. jejuni* accounting for 87.5% of the isolates which were resistant to erythromycin and produces betalactamase at 79.2% and 12.5%, respectively.[27] Furthermore, a study in the western part of Nigeria had reported the prevalence of *Campylobacter* spp. at 7% in humans[21] (Table 2).

Reports in Animals, Food of Animal Origin, and Water from Northwest, Nigeria

The prevalence of 30% for *Campylobacter* species in poultry has been reported in Sokoto State, Nigeria where the possibility of improper identification using conventional method alone was revealed.[1,7] In another study, a prevalence of 81.9% for *Campylobacter* species in raw poultry meat has been reported with *C. jejuni*, *C. coli*, and *C. lari* accounting for 60.9%, 28%, and 7% of the isolates, respectively, while "other thermophilic species" were at 4.1%.[29] Furthermore, a prevalence of 20.1% in goats has been reported in Sokoto State with *C. jejuni*, *C. coli*, *C. lari*, *C. upsaliensis*, and *C. sputorum* accounting for the 62.1%, 21.3%, 8.8%, 4.8%, and 3.0% of the isolates, respectively.[28] Meanwhile, *Campylobacter* species have been considered a potential agent of ovine enteritis and abortion with the report of 18.0% prevalence in sheep in Sokoto State.[30] The isolates were 79.6%, 44.6%, and 72.7% *C. jejuni*, *C. jejuni* biotype, and *C. coli* biotype, respectively.[30] There has been a report of 92.67% *Campylobacter* species prevalence in pigs with *C. coli*, *C. jejuni*, *C. upsaliensis*, and *C. hyointestinalis* accounting for the 78.71%, 14.03%, 5.40%, and 1.50% of the isolates, respectively.[31] *Campylobacter* infection has been reported in dogs and cats at 27.7% and 18.3%, respectively,

Table 2. Prevalence and Distribution of *Campylobacter* Species Infection in Southwest, Nigeria

S.No.	Sources	Prevalence in %	Species	Sample Size	Method of Diagnosis	State	Reference
1	Poultry	30	*C. coli* biotype I at 66.66%, *C. jejuni* biotype I and II at 20.00% and 6.67%, respectively	50 fecal	Culture and biochemical test	Lagos	[17]
2	Poultry	5.3	*C. coli*	150 fecal	Culture & API campy kits	Lagos	[16]
3	Layers	16.8-22%	*C. coli*, other *Campylobacter* spp. and *C. jejuni* were 90%, 10%, and 0% respectively	550 cloacal swab	ModifiedcultureandPCR,genotypic characterization, and antibiotics resistance profiling	Ogun State	[20]
4	Animals, pig, chicken sheep, and guinea fowl	14 7.1 25 7.1 60.7	*C coli* biotype I and II at 100% and 17%, respectively, and *C jejuni* biotype 1%.	200 animals	Culture and biochemical test	Lagos	[22]
5	Cattle and chicken	20.4	*C. coli* 100%	250	Culture and biochemical test	Oyo	[18]
6	Animals, poultry, cattle, sheep, goat, pig, dog, and humans	15.4, 15, 6.25, 12.5, 27.5, 20, and 7	*C. jejuni* biotypes I and II at 70.9% and, 9.0%, respectively. *C. coli* and *C. fecalis* at 12.7% and 7.2%, respectively	248 fecal samples, 156 poultry, 20 cattle, 16 sheep, 6 goats, 40 pigs, 10 dogs, and 200 humans	Culture and biochemical test		[21]
7	Chicken	96.0	*C. jejuni* 96%	Meat	Culture and biochemical test	Oyo	[19]
8	Children with diarrhea	16	*C. jejuni* 87.5% and resistance to erythromycin and betalactamase production at 79.2% and 12.5%, respectively	145 stools		Lagos	[27]
9	Children below 5 years	0.5	*C. coli*	602	Culture	Osun	[23]
10	Diarrheic children	0.6 by culture and 43.8 molecular	*C. jejuni* 72% and *C. coli* 28%. *C. jejuni* biotypes I (44.4%) and II (55.6%) and all *C. coli* biotype I	57 cultured samples and 815 stools	Culture and PCR	Osun	[25]
11	Diarrheic patients	8.2	*C. jejuni* 56%. *C. coli* 44%	306 stools	Culture and biochemical test	Kwara	[47]
12	Diarrheic children and without diarrhea	19.1 and 6	*C. coli* 53.3%	300 and 100 stools	Culture	Ile-Ife, Nigeria	[24]
13	HIV patients	68	*C. upsaliensis, C. jejuni, C. lari, C. coli, C. fetus* at 26.7%, 25.0%, 19.2%, 16.7%, and 12.5%, respectively	100 stool	Culture and Kirby–Bauer disk Diffusion	Oyo	[26]

with *C. upsaliensis* and *C. jejuni* accounting for 89.5% and 23.1% of the isolates in dogs, respectively, while 74.4% and 21.1% were in cat in the same order.[32] A prevalence of *Campylobacter* species at 4.8% in raw milk samples from lactating cows in Sokoto has been reported with *C. jejuni* and *C. jejuni* biotype I, as the contaminating species with the highest contamination rates at 5.4% in White Fulani breed and 6.1% in the dry season.[32] In Sokoto, State, Nigeria, a study has also revealed a 52.70% prevalence of *Campylobacter* in groundwater samples with *C. jejuni, C. coli,* and *C. hyointestinalis* accounting for the 58.97%, 28.21%, and 12.82% of the isolates, respectively.[9] Meanwhile, there had been an earlier reported 68.75% prevalence for *Campylobacter* species in surface water with *C. jejuni*, *C. coli*, *C. fetus,* and *C. hyointestinalis* at 54.55%, 36.36%, 4.55%, and 4.55% prevalence, respectively;[33] a pointer to the significant of the use of treated water in the prevention of campylobacteriosis nationwide. The prevalence of *Campylobacter fetus* subsp. *jejuni* at 12.3% and 7.1% in live birds and eviscerated carcasses, respectively, have been reported in Zaria, Nigeria, with high rates in free-ranged birds and in slaughtered poultry immersed in boiling water before dressing.[34] A study of thermophilic campylobacter species in broilers had reported 51.1% prevalence with *C. jejuni, C. coli,* and *C. lari* constituting 62.6%, 21.6% and, and 15.8% of the isolates, respectively, and were resistant to the tested antibiotics except chloramphenicol.[35]

In Zaria, Kaduna State, a prevalence of 16.1% of *Campylobacter* species in milk product "nunu" had been reported.[36] *C. coli* and *C. jejuni* were at 10.5% and 5.6% prevalence, respectively, and the isolates were resistant to imipenem, gentamicin, and erythromycin at 0%, 5%, and 100%, respectively, while MDR was at 39%.[36] (Table 3).

Reports in Humans from Northwest, Nigeria

A study in Sokoto has reported *Campylobacter* infection in humans at 55% prevalence with 39%, 37%, and 24% prevalence for *C. coli*, *C. lari*, and *C. jejuni*, respectively.[1] Furthermore, 62.67% prevalence had also been reported in Kebbi, State with *C. coli*, *C. jejuni*, *C. upsaliensis*, *C. hyointestinalis*, and *C. lari* accounting for the 60.63%, 24.50%, 7.45%, 5.32%, and 2.13% of the isolates, respectively.[30] The prevalence of 70% and 43% have been reported in pregnant and nonpregnant women of reproductive age, respectively, in Sokoto State, Nigeria with *C. lari*, *C. coli*, and *C. jejuni* accounting for 56%, 32%, and 13% of the isolates, respectively, among the pregnant women and 16%, 60%, and 24% in nonpregnant women in the same order.[5] A study has reported a 19.6 % prevalence in diarrhoeic HIV patients in Kaduna State with the use of culture and API campy kits.[37] Furthermore, a prevalence of 15.3% had been reported in diarrheic children in a study on the role of *Campylobacter* as an agent of diarrhea and their characteristics in Zaria, Nigeria.[38] The consumption of chicken within the household, contact with animals, and drinking of untreated well water and canned milk were independently found to be possible sources and risk factors for the infection. Meanwhile, the isolates were reported very sensitive to gentamicin, nalidixic acid, tetracycline, ciprofloxacin, chloramphenicol, erythromycin, co-trimoxazole, and amoxicillin at 100%, 100%, 95%, 92.5%, 90%, 82.5%, 55%, and 50%, respectively[38] (Table 3).

Reports in Animals and Food of Animal Origin from North Central, Nigeria

A study in Plateau State had reported a prevalence of 28% for *Campylobacter* infection in cattle of which 7% and 21% were *C. jejuni* and *C. coli*, respectively.[39] A lower prevalence of 18.5% has also been revealed for *Campylobacter* species in cattle in Plateau

Table 3. Prevalence and Distribution of *Campylobacter* Species Infection in Northwest, Nigeria

S.No.	Sources	Prevalence in %	Species	Sample Size	Method of Diagnosis	State	Reference
1	Poultry	30	*C. coli, C lari* and *C jejuni* at 53, 28, and 18%, respectively	506 cloacal swab	Culture and biochemical test	Sokoto	[1]
2	Poultry	12.3	*C. fetus* subsp. *jejuni*	487 cloacal swabs	Culture and biochemical test	Kadunna	[34]
3	Broilers	51.1	*C. jejuni*, *C. coli*, and *C. lari* at 62.6%, 21.6%, and 15.8%, respectively	270 cloacal swab	Culture and biochemical test	Sokoto	[35]
4	Pig	92.67	*C. coli, C. jejuni, C. upsaliensis*, and *C. hyointestinalis* at 78.71%, 14.03%, 5.40%, and 1.50%, respectively	300 fecal samples	Culture and biochemical test	Kebbi	[31]
5	Goat	20.1	*C. jejuni* 62.1%, *C. coli* 21.3%, *C. lari* 8.8%, *C. upsaliensis* 4.8%, and *C sputorum* 3.0%.	1312 rectal swab	Culture and biochemical test	Sokoto	[28]
6	Sheep	18.0	*C. jejuni* at 79.6% and *C. jejuni* biotype I (44.6%), and *C. coli* biotype I (72.7%)	518 rectal swabs	Culture and biochemical test	Sokoto	[30]
7	Slaughtered Sheep	3.54	*C. fetus* subsp. *jejuni*, *C. coli*, and *C. laridis* were at 79%, 13%, and 8.0%, respectively	1100 samples,	Culture, Gram staining, biochemical test, and liorbiotyping	Kaduna	[41]
8	Dog Cat	27.7 18.3	*C. upsaliensis* 89.5% and 74.4% in dog and cat, respectively, *C. jejuni* at 23.1% and 21.1% in dog and cat, respectively.	141 and 104 fecal from Dog and cats, respectively	Culture and biochemical test	Sokoto	[32]
9	Raw chicken	81.9	*C. jejuni, C. coli lari*, and others at 60.9%, 28%, 7%, and 4.1%, respectively	681 raw poultry	Culture and biochemical test	Sokoto	[29]
10	Milk	16.1	*C. coli* 10.5% and *C. jejuni* 5.6%.	180 nunu	Membrane filtration biochemical test and API campy kits	Zaria, Kaduna	[36]
11	Milk	4.8	*C. jejuni* and *C. jejuni* biotype I	146 raw milk	Culture and biotyping	Sokoto	[32]
12	Eviscerated carcasses	7.1	*C. fetus* subsp. *jejuni*	70 swabs	Culture and biochemical test	Kadunna	[34]
13	Water	52.7	*C. jejuni, C. coli*, and *C. hyointestinalis* at 58.97%, 28.21%, and 12.82%, respectively	74 ground water sample	Culture and biochemical test	Sokoto	[9]
14	Sokoto River.	68.75	*C. jejuni, C. coli, C. fetus,* and *C. hyointestinalis* at 54.55%, 36.36%, 4.55%, and 4.55%, respectively	32 water	Culture and biochemical test	Sokoto	[33]
15	Diarrheic children& without diarrhea	15.3		261 and 100 stools	Culture and antibiotics sensitivity	Zaria	[38]
16	Children and Adult	55	*C. coli, C. lari,* and *C. jejuni* at 39%, 37%, and 24%, respectively	292 fecal swab	Culture and biochemical test	Sokoto	[1]
17	Poultry& Humans	39.1	*C. jejuni, C. coli*, and *C. lari* at 23.8%, 39.4%, and 36.9%, respectively, in poultry at 19.1%, 52.0%, and 28.9% in humans in same order	798 fecal	Culture, biochemical test, and PCR	Sokoto	[7]
18	Pregnant women Nonpregnant women	70 43	*C. lari, C. coli,* and *C. jejuni* at 56%, 32%, and 13%, respectively, *C. coli, C. jejuni, C. lari* at 60% 24%, and 16% respectively	292 fecal swab	Culture and biochemical test	Sokoto	[2]
19	Humans	62.67%.	*C. coli*, *C. jejuni, C. upsaliensis, C. hyointestinalis*, and *C. lari* at 60.63%, 24.50%, 7.45%, 5.32%, and 2.13%, respectively	150 fecal samples	Culture and biochemical test	Kebbi	[31]
20	HIV patients	19.6	*C jejuni, C. coli, C. fetus*, and *C. hyointestinalis*	230 fecal samples	Culture, biochemical test, and API campy kits	Kaduna	[37]

State, Nigeria with 80% and 20% as *C. jejuni* and *C. coli,* respectively, even as 25% and 12.2% prevalence rates were reported in calves and cows, respectively.[48] An overall prevalence rate of 63.5%, 61.7%, and 66.7% in poultry, ducks around wells, and ponds, respectively, have been reported in Makurdi, Benue State, Nigeria.[40] A prevalence of 3.54% has been reported in slaughtered sheep in Kaduna State with isolation rates of 6.8%, 4%, 2.8%, and 0% from intestinal contents, gallbladders, vaginal, and fetuses, respectively.[41] The isolates were characterized as *C. fetus* subsp *jejuni*, *C. coli*, and *C. laridis* at 79%, 13%, and 8%, respectively.[41] A study on cattle offals slaughtered within Gwagwalada abattoir in Abuja, Nigeria, has reported a prevalence of 68% with the isolates sensitive to gentamycin and amoxil but resistant to norfloxacin, rifampicin, chloramphenicol, streptomycin, and ampiclox.[42] A study in Plateau State has also revealed dogs as a carrier of the zoonotic *Campylobacter* infection with a reported prevalence of 14.3%. A significant association was found between the infection and the age of dogs using a standard bacteriological assay.[43] The prevalence of 23.8% has been reported in dogs sampled at Veterinary Clinics Jos, Nigeria, and the isolates were identified with PCR as *C. jejuni*, *C. coli,* and mixed infections at 50.6%, 38.3%, and 11.1%, respectively.[44] Furthermore, a prevalence of 22.2% has also been reported with *C. jejuni* and *C. coli* at 76.8% and 23.2% in poultry, respectively, and 35.8% and 18.5% in cattle in the same order and study area.[45] Apparently healthy Japanese quails at slaughter have been considered a potential risk for *Campylobacter* infection in humans with a reported 31.1% prevalence in Jos, Plateau State, of which the isolates were identified as 81% *C. jejuni* and 19% *C. coli*[46] (Table 4).

Reports in Humans from North Central, Nigeria

A very recent study has revealed the prevalence of *Campylobacter* infection in humans at 9% with *C. jejuni*, *C. coli,* and *C. hyointestinalis* accounting for 66%, 28%, and 6% of the isolates, respectively,, and some of the dominant strains among the isolates were of genetically diverse origin.[39] The isolates were resistant to beta-lactams, fluoroquinolones, tetracyclines, macrolides, and MDR at 42%, 41%, 15%, 2%, and 13%, respectively.[39] A prevalence of 8.2% has been reported in children with diarrheic in Kwara State.[47] In Plateau State, a prevalence of 11.3% has been reported with 52.9%

Table 4. Prevalence and Distribution of *Campylobacter* Species Infection in North Central, Nigeria

S. No.	Sources	Prevalence in %	Species	Sample Size	Method of Diagnosis	State	Reference
1	Duck around drinking water and water	63.5	*C. jejuni* 76.7%, well water and pond water 66.75% and 83.3%, respectively	192 fecal	Culture and biochemical test	Makurdi	[40]
2	Japanese quails	31.1	*C jejuni* 81% and *C coli* 19%	135 intact caeca	Culture and PCR	Plateau	[46]
3	Cattle	18.5	*C. jejuni* 80% as C. coli 20%	352rectalswab	Culture, biochemical test, and PCR	Plateau	[48]
4	Poultry and cattle	22.2	*C. jejuni* 76.8% *C. coli*. 23.2%	1012 fecal	Culture, PCR, multilocus sequence typing, and antibiotics sensitivity	Plateau	[45]
5	Livestock	28	*C. jejuni* and *C. coli* were 7% and 21%, respectively	472 fecal	Culture and whole-genome sequencing	Plateau	[39]
6	Dog	23.8	*C. jejuni* 50.6%, *C. coli* in 38.3% and 11.1%	341 faecal	Culture and multiplex PCR	Plateau	[44]
7	Dog	14.3	Not indicated	105 fecal	Culture and Gram staining	Plateau	[43]
8	Beef	68	Not indicated	75 swabs	Culture and biochemical test	Abuja	[42]
9	Humans	9	*C. jejuni*, *C. coli*, and *C. hyointestinalis* at 66%, 28%, and 6%, respectively	586 human	Culture and whole-genome sequencing	Plateau	[39]
10	Humans	11.3	*C. jejuni* and *C. coli* at 52.9% and 47.1%, respectively	300 human stool	Culture, PCR, multilocus sequence typing, and antibiotics sensitivity	Plateau	[45]

and 47.1% of the isolates as *C. jejuni* and *C. coli,* respectively.[45] The isolates were susceptible to clindamycin, however, the resistance to nalidixic acid, tetracycline, ciprofloxacin, sulfamethoxazole/tri methoprim, erythromycin, azithromycin, streptomycin, gentamicin, and chloramphenicol was reported at 60.7%, 57.2%, 53.1%, 46.2%, 41.4%, 27.6%, 13.1%, 6.9%, and 4.8%, respectively[45] (Table 4).

Reports on Regional Subgrouping of the Studies and Challenges

From the studies, it was revealed that the highest prevalence was in food of animal origin in both southwest and north central regions of the country with 96% and 68% prevalence, respectively, while the highest prevalence was in the water (60.7%) and other risk individuals (45%) in Northwest, Nigeria. On the detection methods, PCR or molecular analysis was done in 11 (21%) of the 53 studies that used culture and phenotypic identification methods. Resistance to antibiotics including MDR was reported in 15 (28%) of the 53 reviewed studies. High frequency of resistance to erythromycin, ciprofloxacin, and tetracycline was reported in food-producing animals and animal products while resistance to cefixine, cephalothine, and erythromycin was more in humans. Meanwhile, high susceptibility was reported for gentamycin, imipenem, and chloramphenicol in animals and clindamycin, amoxi/clavulanic acid, and amikacin in humans (Table 5).

There is still the issue of noninclusion of *Campylobacter* species testing in the routine laboratory check on gastroenteritis in Nigeria. The public health and economic impact including the antibiotics resistance development and resistance gene transfer is believed to be under-reported as a result of discrepancies in isolation methods. There was a paucity of data on the level of awareness of campylobacteriosis by farmers and animal handlers in Nigeria. Moreover, there is a lack of interest or discouragement among researchers due to the ubiquitous nature of the pathogen and difficulties in species isolation. These were associated with the much time and labor, nonavailability of research reagents,

Table 5. Antimicrobial Profile of *Campylobacter* Species from Different Sources in Nigeria

S.No.	Isolates Sources	Antimicrobial Susceptible	Antimicrobial Resistant	Region	Authors
1	Water, chicken, and beef	Ceftriaxone	Tetracycline	Southeast	[14]
2	Chicken and cattle		Erythromycin and ciprofloxacin	Southwest	[18]
3	Chicken meat		Nalidixic acid, gentamicin, and erythromycin	Southwest	[19]
4	Layers		Tetracycline, ciprofloxacin, erythromycin, spectinomycin, and tylosin	Southwest	[20]
5	Children	Erythromycin		Southwest	[24]
6	HIV patients	Amikacin (92.5%), amoxicillin/clavulanic acid (70.0%), ciprofloxacin (92.5%), ertapenem (90.0%), nalidixic acid (69.2%), and aztreonam (55.0%)	Gentamycin (19.2%), chloramphenicol (26.7%), cefixime (31.7%), and cephalothin (39.2%)	Southwest	[26]
7	Children		Erythromycinandbetalactamaseproductionat79.2%and12.5%,respectively	Southwest	[27]
8	Broilers	Chloramphenicol	All isolates were resistant to the tested antibiotics	Northwest	[35]
9	Nunu	Imipenem	Gentamicin 5% and erythromycin 100%	Northwest	[36]
10	Cattle	Gentamycin and amoxicillin	Norfloxacin, rifampicin, chloramphenicol, streptomycin, and ampiclox but showed some effect to ciprofloxacin, levofloxacin an erythromycin	Northwest	[42]
11	Children	Gentamicin (100%), nalidixic acid (100%), tetracycline (95%), ciprofloxacin (92.5%), chloramphenicol (90%), and erythromycin (82.5%).		Southwest	[38]
12	Birds	Gentamycin	Cephalothin 84%, cephalexin 61%, ampicillin 58%, streptomycin 43%, cotrimoxazole 43%, perfloxacin 9%, ofloxacin 5%, ciprofloxacin 5%	North central	[11]
13	Cattle	Gentamycin and amoxicillin	Norfloxacin, rifampicin, chloramphenicol, streptomycin, and ampiclox but showed some effect to ciprofloxacin, levofloxacin, and erythromycin	North central	[42]
14	Humans		Betalactams (42%) fluoroquinolones (41%), tetracyclines (15%), and lmacrolides (2%)	North central	[39]
15	Humans	Clindamycin	Nalidixicacid(60.7%),tetracycline(57.2%),ciprofloxacin(53.1%),sulfametho xazole/trimethoprim (46.2%), and erythromycin (41.4%)	North central	[45]

high cost of molecular diagnostic equipment, poor technical know-how, and inadequate research facilities and enabling environment.

DISCUSSION

This is the first attempt in providing a retrospective insight on the range and mean prevalence of *Campylobacter* species infection in animals, food sources, and humans in Nigeria, with emphasis on the need for a One Health approach to the prevention and its control. The report has revealed the need to narrow the gap between *Campylobacter* infection research in humans and animals, especially poultry which currently stood at 29% and 49%, respectively, and to further expand the studies in food of animal origin as well as water. It has also revealed the likely under-reported burden of campylobacteriosis in Nigeria as data were only found in 4 out of the 6 geopolitical zones of the country. Meanwhile, the risk practices including open defecation especially in rural communities could have contributed to the spread of *Campylobacter* organisms through human feces and general contamination of the environment.[1] Moreover, high numbers of human populations in many of the states in the regions were not provided with basic healthcare facilities including good water supply which has been reported as potential carriers of *Campylobacter* species.[9] The prevalence range of 5.3-60.7% in poultry was in agreement with the reports of 22.5% in Ghana.[49] Similar prevalence reports including that of 6.87% and 18.3% in children and dogs, respectively, in Brazil, were within the revealed range of 0.5%-43.8% and 14.3%-27.7% in children and companion animals in the same order.[50] The similarities or differences have been associated with many factors including the systems of livestock production, the level of personal, and environmental hygiene.

In Nigeria, the differences in the prevalence; the least 12.6%, in southwest, followed by 23.3% and 33.6% in the north central and northwest regions, respectively, could be attributed to many factors including the sample population, geographical location, species of animal, and management system. The extensive system of broiler production which discourages environmental contamination and disease transmission is practiced more in the southwest and southeast regions than in the northwest and north central regions where local birds are mostly raised on free range and some are transported into the country from the border states of Niger republic.[1,34]

The highest prevalence of 23% for companion animals in the northwest, followed by 20% in the southwest and the least 19.5% in north central can also be a reflection of keeping the practice of pet animals and the consequential environmental contamination in these regions, especially in the north where cats are kept for companionship and rodent control.[50] Furthermore, the high prevalence of 60.7% in water from northwest of the country compared to 8.8% in southeast could be a reflection of higher environmental contamination in the north where 85% of the surface water and rivers have been reported contaminated with *Campylobacter* spp. This may be associated with interactions of waterfowl and wild birds in the water bodies, disposal of untreated sewage, and contamination via rain-related runoff.[33,40] The differences in levels of *Campylobacter* prevalence in the carcass and other food of animal origin could be a product of colonization in slaughter animals, meat, and milk processing hygiene as well as the sampling techniques.[4] This was further revealed with the highest prevalence of 96% in southwest region where poultry production and processing are much in practice. Furthermore, age, diarrheic conditions, and exposure to risk practices may have influenced the results in humans. This can be explained by the highest prevalence of 15.3% and 45.0% in children and other risk groups, respectively, in the northwest region followed by 14.4% and 27.7% in the same order in the southwest region. These 2 regions are the areas with much interaction between animals and humans, especially in the production of large and small animals, respectively. Other factors like small sample size may have affected the prevalence as seen in north central and southeast with 10.2% and 18.5% prevalence rates, respectively.

The detection of *C. jejuni* and *C. coli*, the well-known pathogenic species as the most prevalent species in humans and animals in this study, was in agreement with a similar report in Ethiopia and this could pose a huge burden of campylobacteriosis in Nigeria including the development and transfer of antibiotics resistant gene. Since most of the isolates were reported with a high frequency of resistance to the commonly used antibiotics in the management of gastroenteritis, such as erythromycin, ciprofloxacin, and tetracycline, regular antibiotics sensitivity testing should be encouraged in the management of campylobacteriosis.

This study has revealed the range and pooled prevalence with a retrospective insight on the distribution of *Campylobacter* species infection in an animal, food matrix, and humans in Nigeria. It has given credence that the infection in animals could have significantly resulted in cases of acute gastroenteritis and antimicrobial resistance in humans, especially in children and other at-risk individuals in the country. Reduction and control strategies should be targeted toward reduction in the risk practices, provision of adequate social amenities, and improved personal and environmental hygiene and sanitation in the country. There is a need for increased collaboration between human medics and veterinarians on *Campylobacter* research to the level of molecular and comparative analysis of isolates from animals and humans in Nigeria, especially in the south-south and northeast regions of the country where no data is in existence. Accurate diagnosis and rational use of antimicrobials must be prioritized as well as awareness creation on infection prevention and control using the "One Health" approach.

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