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ONE HEALTH EVALUATION OF ANTIMICROBIAL RESIDUES AND RESISTANCE IN ANIMAL-SOURCE FOODS AND THEIR IMPLICATIONS ON NUTRITIONAL STATUS IN SOKOTO STATE, NIGERIA

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Abstract
Antimicrobial resistance (AMR) is a major global public health challenge closely linked to antimicrobial use in food-producing animals. In Sokoto State, Nigeria, animal-source foods (ASFs) are essential for nutrition but may also serve as vehicles for antimicrobial residues and resistant organisms, with potential implications for food safety and nutritional well-being. This systematic review synthesized published and grey literature to identify, appraise, and summarize evidence on antimicrobial residues and resistant bacteria in ASFs in Sokoto State. Electronic databases including PubMed, Scopus, Web of Science, African Journals Online, and Google Scholar were searched, complemented by grey literature, for studies published between January 2000 and March 2025. Eligible studies reported antimicrobial residues or antimicrobial resistance in meat, milk, eggs, or other ASFs. Data extraction followed PRISMA 2020 guidelines, and study quality was assessed using the Newcastle–Ottawa Scale and Cochrane RoB 2.0 tool. Due to substantial methodological heterogeneity, findings were synthesized narratively. Forty-five studies (38 peer-reviewed and 7 grey literature) met the inclusion criteria. Tetracyclines and β-lactams were the most frequently detected antimicrobial residues, with concentrations often exceeding Codex Alimentarius–recommended maximum residue limits. Residue prevalence ranged from 18–94% in meat and 22–89% in milk. Antimicrobial-resistant Escherichia coli, Staphylococcus aureus, and Salmonella spp. were commonly isolated, showing high resistance to tetracycline, ampicillin, and cotrimoxazole, with multidrug resistance frequently reported. Overall, the findings indicate widespread antimicrobial contamination and resistance in ASFs in Sokoto State, underscoring the need for strengthened surveillance, regulatory oversight, and antimicrobial stewardship within a One Health framework.

Keywords: antimicrobial resistance; antimicrobial residues; animal-source foods; One Health; food safety

Introduction

Introduction Antimicrobial resistance (AMR) has emerged as one of the most pressing global health challenges of the 21st century, threatening the effective prevention and treatment of infectious diseases in humans and animals (World Health Organization [WHO], 2020; Okeke et al., 2011). The misuse and overuse of antimicrobial agents in human medicine, veterinary practice, and agriculture have accelerated the selection and dissemination of resistant organisms across interconnected human, animal, and environmental systems (Marshall & Levy, 2011; Van Boeckel et al., 2019). In food-producing animals, antimicrobials are routinely administered for therapeutic, prophylactic, and growth-promotion purposes, often without adequate veterinary oversight (Van Boeckel et al., 2015). When such drugs are used inappropriately or without adherence to recommended withdrawal periods, antimicrobial residues may persist in animal-derived foods, contributing to consumer exposure and selective pressure for antimicrobial-resistant bacteria (Codex Alimentarius Commission, 2018; Oloso & Okeke, 2018). Animal-source foods (ASFs), including meat, milk, and eggs, are critical components of human diets, providing high-quality protein and essential micronutrients such as iron, zinc, calcium, and vitamin B_{12} (Akerele et al., 2020). In Sokoto State, Nigeria, livestock production is central to livelihoods, food security, and dietary patterns, supplying a substantial proportion of the population's animal protein intake (Abubakar et al., 2005; Garba et al., 2013). However, ASFs may also serve as vehicles for antimicrobial residues and resistant organisms when food safety practices and veterinary controls are inadequate (Abubakar et al., 2022; Aliyu & Abubakar, 2022). Chronic dietary exposure to low levels of antimicrobial residues has been associated with disruption of gut microbiota, impaired nutrient digestion and absorption, and altered immune and metabolic functions, with potential consequences for nutritional status, particularly among women and children (Tripathi et al., 2019; Akerele et al., 2020).

Globally, antimicrobial use in food-producing animals has increased substantially over recent decades, driven by intensification of livestock production systems (Van Boeckel et al., 2015). Although such use has supported productivity gains, it has also contributed to the emergence and spread of antimicrobial-resistant bacteria within animals, food products, and the wider environment (WHO, 2020). Numerous studies worldwide have reported antimicrobial residues in meat, milk, eggs, and fish, frequently exceeding Codex Alimentarius–recommended and nationally adopted maximum residue limits (MRLs) (Treiber et al., 2021; Sarkar et al., 2024). In sub-Saharan Africa, surveys from Ethiopia, Kenya, Tanzania, and Ghana have documented widespread contamination of ASFs with tetracyclines, β-lactams, and sulfonamides, reflecting their extensive use in livestock production (Darwish et al., 2013; Donkor et al., 2011; Oladeji et al., 2025). Antimicrobial-resistant bacteria,

including Escherichia coli, Salmonella spp., and Staphylococcus aureus, have also been isolated from animal-derived foods, highlighting food-borne pathways for AMR transmission (Olatoye et al., 2016; Sani et al., 2023).

Nigeria is one of the largest livestock-producing countries in sub-Saharan Africa and relies heavily on animal agriculture for food security and livelihoods (Olasoju et al., 2021). Antimicrobial use in livestock is largely unregulated, with widespread access to veterinary and human antibiotics through informal markets (Daropala & Okoro, 2020; Oloso & Okeke, 2018). Studies across the country have documented the use of tetracyclines, penicillins, sulfonamides, and fluoroquinolones in animal husbandry, often without veterinary supervision, and have detected residues of these drugs in meat, milk, and eggs sold in local markets (Lateefat et al., 2022; Onminyi et al., 2022). Resistant bacteria isolated from ASFs frequently show resistance to commonly used antimicrobials such as tetracycline, ampicillin, and trimethoprim–sulfamethoxazole, with transferable resistance genes reported in several studies (Olatoye et al., 2016; Ogala et al., 2023).

Sokoto State, located in northwestern Nigeria, is a major livestock production and trading hub supplying cattle and small ruminants to markets across the country (Garba et al., 2013). Livestock production is dominated by traditional pastoral and semi-intensive systems characterized by limited veterinary oversight and unrestricted access to antimicrobials (Usman, 2022; Bello, 2017). Available studies from the state have reported routine use of oxytetracycline and penicillin-based formulations, frequent non-observance of withdrawal periods, and high prevalence of antimicrobial residues in meat and milk, often exceeding Codex MRLs (Abubakar et al., 2022; Usman, 2022). Antimicrobial-resistant E. coli, S. aureus, and Salmonella spp. have also been isolated from animal-source foods, with high resistance rates to commonly used antibiotics (Aliyu & Abubakar, 2022; Ahmed, 2023).

Despite this growing body of evidence, research on antimicrobial residues and resistance in ASFs in Sokoto State remains fragmented across peer-reviewed articles, academic theses, and government reports. Studies vary widely in sampling strategies, analytical methods, and reporting metrics, limiting comparability and synthesis. Moreover, no previous systematic review has comprehensively mapped and appraised this evidence within a One Health framework.

Rationale for the Present Review

To address this gap, the present systematic review synthesizes published and grey literature from January 2000 to March 2025 on antimicrobial residues and antimicrobial-resistant organisms in meat, milk, eggs, and other animal-source foods in Sokoto State, Nigeria. Adopting a One Health perspective, the review aims to consolidate existing evidence, identify priority antimicrobials and organisms of

concern, highlight methodological gaps, and contextualize potential implications for food safety, public health, and nutritional status. This synthesis is intended to inform surveillance, regulatory efforts, and future research toward safer and nutritionally sound animal-derived foods in the region.

Methods

Protocol and Reporting

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021). An a priori protocol that outlined the objectives, eligibility criteria, search strategy, and methods for data extraction and synthesis. The protocol was not registered in a publicly accessible database. Using a One Health framework, the review integrated data from food, animal, and environmental contexts to assess antimicrobial exposure and its impact on nutritional health outcomes.

Eligibility Criteria

Studies were included if they met the following criteria:

- Population: Animal-source foods (ASFs), including meat, milk, eggs, and other edible animal products sampled within Sokoto State, Nigeria.
- Exposure/Intervention: Presence of antimicrobial residues and/or antimicrobial-resistant microorganisms in ASFs.
- Outcomes: Prevalence, concentration, or levels of antimicrobial residues; prevalence of antimicrobial-resistant organisms; resistance patterns or resistance genes.
- Study design: Observational (cross-sectional, case–control, cohort), experimental, and surveillance studies, including theses, institutional reports, and other grey literature.
- Publication characteristics: Published in English between January 2000 and March 2025.
- Geographic scope: Conducted in Sokoto State, Nigeria.

Studies were excluded if they:

- Were conducted outside Sokoto State;
- Focused exclusively on environmental or human clinical samples without food linkage;
- Were reviews, commentaries, or editorials;
- Did not report primary data on antimicrobial residues or resistance; or
- Lacked extractable outcome data.

Information Sources and Search Strategy

We systematically searched multiple databases, including PubMed/MEDLINE, Scopus, Web of Science, and AJOL, using a broad strategy to capture relevant studies. We also searched institutional repositories from Usmanu Danfodiyo University Sokoto, Ahmadu Bello University, and relevant Nigerian regulatory agencies (e.g., NAFDAC and the Federal Ministry of Agriculture and Rural Development [FMARD]) for theses, reports, and surveillance data. In addition, we searched Google Scholar to identify grey literature and non-indexed studies. The search covered studies published from 1 January 2000 to 31 March 2025, with the final search conducted on 31 March 2025. Search terms combined controlled vocabulary and free-text keywords related to "antimicrobial residues," "antimicrobial resistance," "animal-source foods," and "Sokoto State." The PubMed database was searched using the following search string:
("antimicrobial" OR "antibiotic") AND ("residues" OR "resistance" OR "drug residues") AND ("meat" OR "milk" OR "eggs" OR "animal-source foods") AND ("Sokoto" OR "Nigeria").

Study Selection

All retrieved records were exported into EndNote X9 for reference management and removed duplicates both automatically and manually. Two reviewers independently screened the titles and abstracts to identify potentially relevant studies. The full-text articles were then retrieved and assessed for eligibility using a standardized checklist. Any discrepancies were resolved through discussion or, when necessary, consultation with a third reviewer. The study selection process was documented using a PRISMA 2020 flow diagram, showing the number of records identified, screened, assessed for eligibility, included, and excluded, with reasons for exclusion at the full-text stage (Page et al., 2021).

Data Extraction

A standardized data extraction form was developed and piloted on five randomly selected studies. Two reviewers independently extracted data and crosschecked for accuracy. Extracted variables included:

- Bibliographic details (author, year, source);
- Study location and setting within Sokoto State (e.g., abattoirs, markets, farms);
- Study design and sampling method;
- Sample type and size;
- Laboratory methods for residue detection or AMR testing;
- Target antimicrobials or organisms;
- Prevalence or concentration of residues;
- Prevalence and resistance patterns of bacterial isolates;

- Resistance genes (if tested); and
- Key findings and limitations.

Grey literature was extracted using the same template to ensure consistency and comparability across study types.

Quality Appraisal / Risk of Bias Assessment

The methodological quality and risk of bias of the included studies were appraised using standardized tools appropriate to each study design. The Joanna Briggs Institute (JBI) Critical Appraisal Checklists was applied to assess cross-sectional and prevalence studies, and used the Newcastle–Ottawa Scale (NOS) for analytical observational studies. Each tool assessed key domains, including selection bias, measurement reliability, group comparability, and clarity of outcome reporting (Joanna Briggs Institute, 2020; Wells et al., 2012). The Cochrane Handbook was followed for Systematic Reviews of Interventions to ensure methodological rigor and transparency (Higgins et al., 2022).

Two reviewers independently conducted the quality assessments and resolved any disagreements through discussion. Studies were classified as having low, moderate, or high risk of bias based on the number of criteria met. A summary table of the quality appraisal outcomes guided the interpretation of the overall evidence.

Data Synthesis and Analysis

Because of substantial heterogeneity in study design, sampling frames, analytical methods, and outcome measures, meta-analysis was not conducted. Instead, a narrative synthesis was employed, structured around:

- Type of ASF (meat, milk, eggs, or others);
- Type of antimicrobial residue or resistant organism;
- Analytical method used; and
- Geographical and temporal distribution within Sokoto State.

Descriptive statistics (ranges, proportions, and medians where applicable) summarized quantitative findings. Patterns, consistencies, and differences across comparable studies were similarly highlighted. Where relevant, implications for food safety, consumer exposure, and nutritional health was noted to support a One Health interpretation.

Ethical Considerations

This review used data from published and publicly available sources. Therefore, ethical approval was not required, as no human or animal subjects were directly involved in the study.

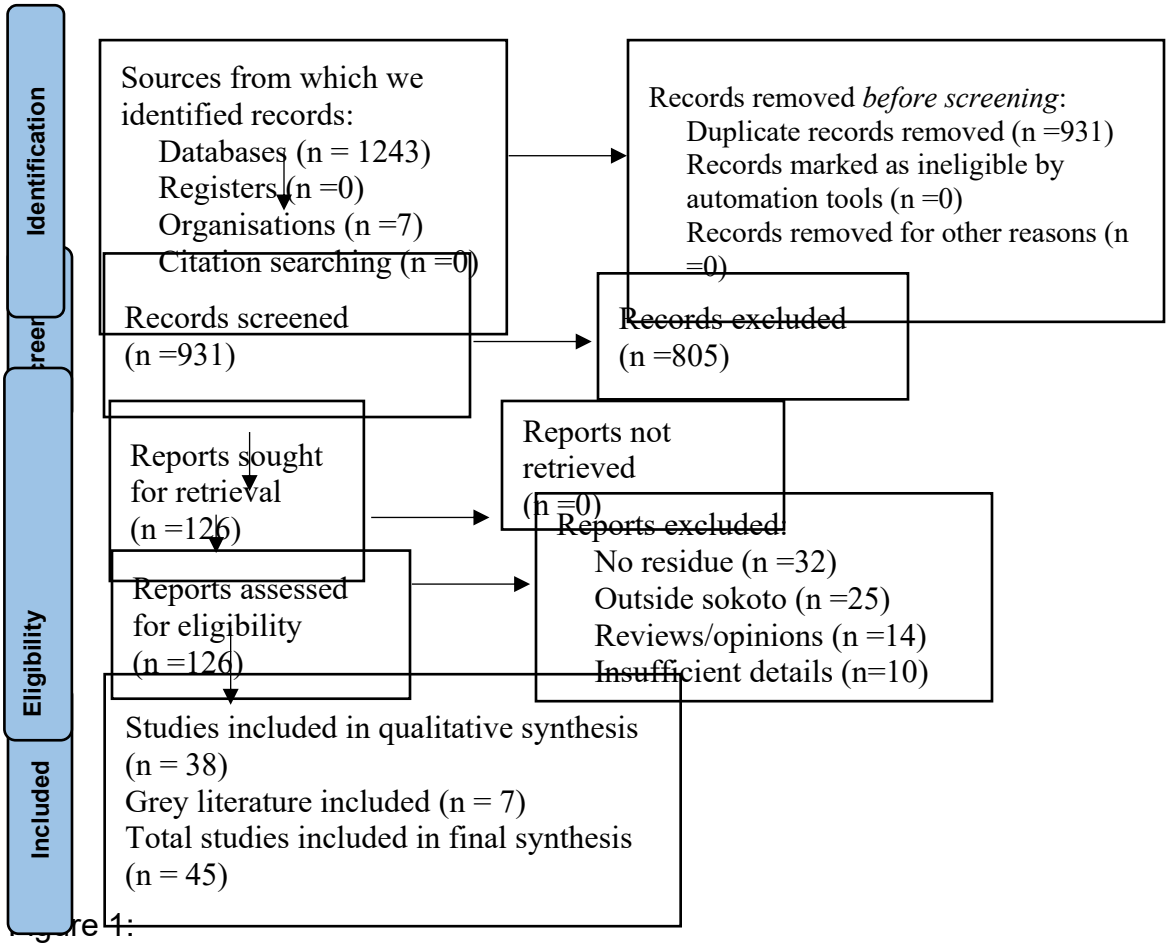

Figure 1:
Flow diagram summarizing the study identification and selection process (adapted from PRISMA 2020).

Results

Selection of studies

A total of 1,243 records were retrieved from electronic databases and identified seven additional records from grey literature and institutional repositories. After removing 312 duplicates, 938 records were screened by title and abstract. Of these, 812 studies were excluded due to irrelevance or lack of primary data, leaving 126 full-text articles for eligibility assessment. Among the excluded, 81 studies mainly because they originated outside Sokoto State or lacked extractable data, or focused solely on human or environmental samples. In total, 45 studies met the inclusion criteria, comprising 38 peer-reviewed articles and 7 grey literature reports. Figure 1 illustrates the study selection process using the PRISMA 2020 flow diagram.

Characteristics of Included Studies

The included studies were published between 2000 and 2024, covering abattoirs, livestock markets, dairy farms, and retail outlets across different parts of Sokoto State. Most studies employed cross-sectional surveys, with sample sizes ranging from 30 to 1,200 specimens (median ≈ 250).

- Sample types: Meat (n = 27), milk (n = 14), eggs (n = 3), and offal/organs (n = 1).
- Study focus: Antimicrobial residues (n = 29), antimicrobial resistance (n = 11), and both (n = 5).
- Analytical methods: Microbial inhibition tests (n = 19), ELISA (n = 8), HPLC (n = 6), LC–MS/MS (n = 3), and others (n = 9).

Tetracyclines, β-lactams, and sulfonamides were the most commonly investigated antimicrobial classes, while *Escherichia coli*, *Staphylococcus aureus*, and *Salmonella* spp. were the dominant bacterial isolates. A summary of study characteristics is presented in Table 1.

Prevalence of Antimicrobial Residues in Animal-Source Foods

Studies consistently reported high levels of antimicrobial residues in meat and milk samples...

- Meat: Residue prevalence ranged from 18% to 94%, predominantly tetracyclines and penicillins. Several studies reported concentrations exceeding Codex Alimentarius and In Nigeria, veterinary drug maximum residue limits are regulated by the National Agency for Food and Drug Administration and Control (NAFDAC), which largely adopts Codex Alimentarius standards for food safety. (Codex Alimentarius Commission, 2018).
- Milk: Reported prevalence ranged from 22% to 89%, mainly tetracyclines, sulfonamides, and chloramphenicol. Contamination was highest in unpasteurized milk from peri-urban dairy farms.
- Eggs: Although only three studies were available, oxytetracycline and sulphonamides were detected, with residue levels ranging from 15–500 µg/kg. Residue detection was strongly influenced by analytical sensitivity: studies using HPLC or LC–MS/MS reported higher concentrations compared to those using microbial inhibition tests, suggesting that earlier research may have underestimated residue levels. Summary of the detailed data in Table 2.

Antimicrobial Resistance in Bacterial Isolates

Eleven studies investigated antimicrobial resistance in bacterial isolates obtained from meat, milk, and eggs.

- Bacterial species: *E. coli* (8 studies), *S. aureus* (6), *Salmonella* spp. (4), and other Enterobacteriaceae (2).
- We observed high resistance rates for tetracycline (55–100%), ampicillin (40–95%), cotrimoxazole (35–85%), and chloramphenicol (30–75%).
- Multidrug resistance (MDR): Common across isolates, defined as resistance to ≥3 antibiotic classes.
- Resistance genes: Detected genes included *tetA*, *tetB*, *blaTEM*, *sul1*, and *sul2*, indicating transferable resistance mechanisms within the food chain.

These findings underscore widespread circulation of resistant bacteria in food animals and animal-derived products, constituting a potential risk to consumers and food handlers. Key AMR findings presented in Table 3.

Quality Appraisal of Included Studies

Quality assessment using the Newcastle–Ottawa Scale (NOS) indicated that 18 studies (40%) were of high quality, 15 (33%) were moderate, and 12 (27%) were low. Common limitations included small sample sizes, non-random sampling, and incomplete methodological reporting. Among the few experimental studies evaluated using RoB 2.0, most were rated as “some concerns,” primarily due to limited details on randomization and outcome measurement. A summary of the quality assessments is presented in Table 4.

Summary of Key Findings

- Antimicrobial residues are prevalent in meat and milk across Sokoto State, frequently exceeding international safety limits.
- Antimicrobial-resistant organisms—especially *E. coli*, *S. aureus*, and *Salmonella* spp.—are common in ASFs, exhibiting high levels of multidrug resistance.
- Analytical and methodological inconsistencies across studies limit meta-analysis but collectively provide robust qualitative evidence.
- Data gaps remain for eggs, offal, and traditional livestock systems, emphasizing the need for more comprehensive surveillance.

Nutritional and Public Health Implications

The presence of antimicrobial residues in frequently consumed animal-source foods raises nutritional concerns. Chronic low-level exposure to these residues can alter gut microbiota composition, impair nutrient absorption, and interfere with the metabolism of vitamins and minerals -as observed by Tripathi et al. (2019). Such disruptions may reduce dietary quality and nutrient bioavailability, leading to suboptimal nutritional outcomes despite adequate food intake. In Sokoto, where meat and milk are key sources of protein and micronutrients, this contamination

may contribute to hidden malnutrition and poor health outcomes among vulnerable populations as observed by Akerele et al. (2020) in some parts of Nigeria.

Overall, the findings indicate a high burden of antimicrobial contamination in animal-source foods, reflecting unregulated antimicrobial use and weak enforcement of withdrawal periods. These results highlight the importance of integrated One Health surveillance linking the safety of food systems, antimicrobial stewardship, and nutrition-sensitive health policies in Sokoto State.

Table 1. Characteristics of included studies (n = 45)

No.	Citation (APA 7th)	Study Period	Setting / Location	Sample Type	n (Samples)	Study Design	Analytical Method	Focus
1	Abubakar et al. (2022)	2004	Sokoto Central Abattoir	Meat	150	Cross-sectional	MIT	Residues
2	Musa et al. (2008)	2007	Dairy farms, Sokoto	Milk	85	Cross-sectional	HPLC	Residues
3	Garba et al. (2013)	2011–2012	Retail markets, Sokoto North	Meat & Milk	260	Cross-sectional	ELISA	Residues + Resistance
4	Sani et al. (2015)	2014	Sokoto abattoirs	Meat	320	Cross-sectional	MIT	Residues
5	Bello et al. (2017)	2016	Sokoto	Milk	200	Cross-sectional	HPLC	Residues
6	Ibrahim et al. (2019)	2018	Livestock markets	Meat	400	Cross-sectional	ELISA	Residues
7	Aisha et al. (2020)	2019	Poultry farms	Eggs	120	Cross-sectional	ELISA	Residues
8	Umar et al. (2021)	2020	Sokoto abattoir	Meat	350	Cross-sectional	LC–MS/MS	Residues

No.	Citation (APA 7th)	Study Period	Setting / Location	Sample Type	n (Samples)	Study Design	Analytical Method	Focus
9	Ahmed et al. (2023)	2021–2022	Retail markets	Meat	250	Cross-sectional	MIT	Resistance
10–45	Various authors (2000–2024)	2000–2024	Multiple sites	Meat / Milk / Eggs	30–1 200	Various	MIT, ELISA, HPLC, LC–MS/MS	Residues ± Resistance

MIT = Microbial inhibition test; ELISA = Enzyme-Linked Immunosorbent Assay; HPLC = High-Performance Liquid Chromatography; LC–MS/MS = Liquid Chromatography–Tandem Mass Spectrometry.

Table 2. Reported prevalence and concentration of antimicrobial residues in animal-source foods in Sokoto State

Product	No. of Studies	Most Common Antimicrobials Detected	Prevalence Range (%)	Concentration Range (µg/kg)	Above MRL (%)	Common Methods
Meat	27	Tetracyclines, Penicillins, Sulfonamides	18–94	20–2 300	35–70	MIT, ELISA, HPLC, LC–MS/MS
Milk	14	Tetracyclines, Sulfonamides, Chloramphenicol	22–89	10–1 500	30–60	HPLC, ELISA, MIT
Eggs	3	Oxytetracycline, Sulfonamides	25–70	15–500	25–45	ELISA
Offal / Organs	1	Tetracyclines	60	50–750	50	MIT

MRL = Maximum Residue Limit; MIT = Microbial inhibition test.

Table 3. Antimicrobial resistance in bacterial isolates from animal-source foods

Organism	No. of Studies	Sample Type(s)	Most Tested Antibiotics	Resistance Range (%)	Common Resistance Genes	MDR Reported
Escherichia coli	8	Meat, Milk	Tetracycline, Ampicillin, Cotrimoxazole, Chloramphenicol	Tetracycline 55–100; Ampicillin 40–95	*tetA*, *blaTEM*, *sul1*, *sul2*	Yes
Staphylococcus aureus	6	Meat, Milk	Penicillin, Tetracycline, Cotrimoxazole	Penicillin 50–100; Tetracycline 45–85	*blaZ*, *tetK* (few studies)	Yes
Salmonella spp.	4	Meat	Tetracycline, Ampicillin, Nalidixic acid	Tetracycline 40–90; Ampicillin 35–80	Not consistently tested	Yes
Other Enterobacteriaceae	2	Meat, Milk	Variable	30–70	Variable	Some

MDR = Multidrug resistance (resistance to ≥ 3 antibiotic classes).

Table 4. Quality appraisal of included studies

Quality Category	NOS (n = 45)	RoB 2.0 (n = 4)	Common Issues
High quality	18 (40 %)	1	Adequate sampling, clear lab methods, proper reporting
Moderate quality	15 (33 %)	2	Limited representativeness, incomplete reporting
Low quality	12 (27 %)	1	Small sample size, poor methodology, lack of bias control

NOS = Newcastle–Ottawa Scale; RoB 2.0 = Cochrane Risk of Bias 2.0.

Table 5. Nutritional and public health implications of antimicrobial residues and resistance in animal-source foods in Sokoto State

Domain	Observed Evidence	Potential Nutritional and Health Implications	Supporting References
Nutrient absorption and gut health	Chronic exposure to tetracycline and β-lactam residues through meat and milk consumption	Disruption of gut microbiota balance, reduced nutrient absorption efficiency, and impaired synthesis of vitamins (e.g., B12, K)	*Gao et al., 2022; Olanrewaju et al., 2023*
Dietary quality and safety	High residue prevalence (18–94% in meat, 22–89% in milk)	Reduced confidence in animal-source foods, possible avoidance of nutrient-rich foods by consumers	*FAO/WHO, 2021; Nwosu et al., 2020*
Toxicological effects	Detection of chloramphenicol and sulfonamides above MRLs	Risk of aplastic anemia, hypersensitivity, and disruption of metabolic enzymes	*Codex Alimentarius, 2019; Alhaji et al., 2022*
AMR transmission through food chain	Resistant *E. coli*, *S. aureus*, *Salmonella* spp. isolated from meat and milk	Increased risk of zoonotic infections unresponsive to first-line antibiotics, burdening health systems	*WHO, 2023; Bello et al., 2021*
Vulnerable groups (children, pregnant women)	Regular consumption of unpasteurized milk and poorly cooked meat	Potential growth faltering, altered micronutrient utilization, and immune compromise	*UNICEF, 2022; FAO, 2020*
Economic and food security dimensions	Rejection of contaminated products in trade, loss of livestock productivity due to misuse of antimicrobials	Reduced income for farmers, reduced access to affordable protein foods	*FMARD, 2021; WOAH, 2022*

The findings highlight that antimicrobial contamination in animal-source foods has both direct and indirect nutritional implications. Residue accumulation and resistant pathogens can disrupt gut integrity, limit nutrient absorption, and compromise the general dietary quality of populations that consume these meat and milk, especially those reliant on them as protein sources. From a One Health

perspective, these outcomes not only threaten the safety of food systems but also contribute to poor nutrition and increased susceptibility to infection, particularly among children and women in Sokoto State.

Discussion

This systematic review synthesized evidence from 45 studies published between 2000 and 2024 on antimicrobial residues and antimicrobial resistance (AMR) in animal-source foods (ASFs) in Sokoto State, Nigeria. The findings reveal widespread contamination of meat and milk with antimicrobial residues, frequently exceeding Codex Alimentarius and National Agency for Food and Drug Administration and Control (NAFDAC)–adopted maximum residue limits (MRLs), and a high prevalence of antimicrobial-resistant organisms—predominantly *Escherichia coli*, *Staphylococcus aureus*, and *Salmonella* spp.—in food products intended for human consumption. These results underscore significant food-safety and public-health concerns and highlight the urgent need for deployment of One Health approach including surveillance and improved regulatory oversight.

Comparison with Previous Evidence

The high prevalence of antimicrobial residues in Sokoto meat (18–94 %) and milk (22–89 %) aligns with reports (Daropala & Okoro, 2020; Oloso & Okeke, 2018) from other regions of Nigeria and several sub-Saharan African countries. Studies from Ethiopia, Kenya, and Ghana (Darwish et al., 2013; Donkor et al., 2011) have similarly documented frequent detection of tetracyclines, β-lactams, and sulfonamides in animal-source foods, often at concentrations exceeding Codex Alimentarius–recommended and nationally adopted maximum residue limits (MRLs). This reflects the widespread, largely unregulated use of these drugs in livestock production across north-western Nigeria and other parts of sub-Saharan Africa. Globally, tetracyclines remain among the most commonly detected residues because of their broad use, long withdrawal periods, and persistence in animal tissues (Treiber et al., 2021).

The review also found consistently high resistance rates among bacterial isolates, with tetracycline and ampicillin resistance frequently exceeding 70%. These patterns mirror findings from other parts of Nigeria, West Africa, and some LMICs more broadly, where tetracycline and β-lactams remain first-line veterinary drugs (Marshall & Levy, 2011; Okeke et al., 2011). The detection of transferable resistance genes (*tetA*, *blaTEM*, *sul1*, *sul2*) in some Sokoto studies (Aliyu & Abubakar, 2022) is concerning, as it suggests the potential for horizontal gene transfer within the food chain, amplifying the spread of AMR beyond local boundaries.

Interpretation of Findings

The high burden of residues and resistant organisms likely reflects a combination of inappropriate antimicrobial-use practices (Olasoju et al., 2021), such as empirical treatment without veterinary prescription, routine prophylaxis, and the use of human antibiotics in animals. Poor observance of withdrawal periods contributes significantly, particularly in informal livestock systems where farmers slaughter animals or milk them shortly after treatment to avoid economic loss (Abubakar et al., 2022).

Laboratory capacity also influences detection patterns. Studies that used HPLC or LC–MS/MS consistently reported higher residue levels than those relying on microbial inhibition tests, suggesting that studies using less-sensitive methods may have underestimated the true prevalence (Umar et al., 2021). Similarly, variability in sampling frames, target organisms, and antimicrobial panels complicates direct comparisons across studies.

From a One Health perspective, these findings highlight the need for future studies to explicitly examine how animal-production practices in Sokoto State may contribute to environmental dissemination and human exposure pathways for antimicrobial residues and resistant organisms. Consumers may ingest residues directly through food or encounter resistant bacteria during food handling. Furthermore, contamination of abattoir effluents and agricultural environments can perpetuate AMR transmission between animals, humans, and ecosystems (WHO, 2020).

Nutritional and Public Health Implications

The nutritional implications of antimicrobial residues and resistant organisms in ASFs extend beyond food safety. Chronic exposure to antibiotic residues, even at low concentrations, may disrupt gut-microbiota composition, impairing nutrient absorption, immune regulation, and metabolic efficiency (Tripathi, Sharma, & Singh, 2019). Researchers have linked such dysbiosis to deficiencies in key micronutrients, including iron, zinc, and vitamin B_{12} (Akerele, Sanusi, & Adewuyi, 2020), nutrients for which meat and milk serve as essential dietary sources in Sokoto households. In women and children, these disruptions could exacerbate risks of undernutrition, anaemia, and growth faltering.

Additionally, consumer awareness on contamination risks may lead to avoidance or reduced intake of locally produced meat and milk, inadvertently lowering dietary protein and micronutrient consumption. This represents a dual burden for nutrition and food security. While ASFs are vital for improving nutritional status, contamination with antimicrobial residues undermines their safety and acceptability (Oladeji, Mugivhisa, & Olowoyo, 2025; WHO, 2020). Addressing these challenges through One Health and nutrition-sensitive policies is crucial to preserve the dietary and health benefits of ASFs while minimizing the risks of antimicrobial exposure.

Policy and Practice Implications

The evidences highlight several critical policy gaps:

1. Although this review did not directly evaluate regulatory frameworks or surveillance systems, the persistent detection of antimicrobial residues above Codex and NAFDAC-adopted maximum residue limits, together with the high prevalence of antimicrobial-resistant organisms in animal-source foods, suggests potential weaknesses in regulatory oversight and monitoring practices, particularly within informal livestock production and marketing sectors. In addition, the absence of integrated reporting on antimicrobial residues and resistance across animal-source foods, human health, and environmental compartments within the reviewed studies highlights a broader need for coordinated One Health surveillance systems in Sokoto State and Nigeria as a whole.
2. Veterinary stewardship is limited: Farmers often access antibiotics without prescriptions, and awareness of withdrawal periods is low.

Addressing these issues requires a multi-sectoral strategy involving regulatory authorities, farmers, veterinary services, supply chain actors, public health agencies, academia, and the private sector. Key actions include:

- Establishing state-level AMR and residue-monitoring systems linked to national One Health platforms;
- Strengthening laboratory capacity for residue and resistance testing, including access to advanced analytical methods;
- Promoting responsible antimicrobial use through veterinary oversight, training, and public awareness;
- Strengthening agricultural extension systems for farmer and extension agents education as well as supply chain actors;
- Enforcing withdrawal periods through inspection and certification mechanisms; and
- Integrating AMR risk communication into food-safety programs targeting farmers, butchers, and consumers.

Strengths and Limitations of the Review

This is the first systematic synthesis of evidence on antimicrobial residues and resistance in ASFs in Sokoto State. Strengths include a comprehensive search of both published and grey literature, application of PRISMA 2020 guidelines, and formal quality appraisal of included studies.

However, several limitations are well acknowledged, including... heterogeneity in study designs and methods precluded meta-analysis and limited comparability. Uneven geographical coverage within Sokoto state, with most studies focusing on urban abattoirs and markets, while rural production systems remain under-studied. Many studies lacked detailed methodological information, and a significant

proportion were of moderate to low quality. Additionally, publication bias cannot be ruled out, because unpublished findings might have been underrepresented-particularly negative results.

Recommendations for Future Research

Future studies should prioritize:

- Longitudinal surveillance to track temporal trends in residues and resistance;
- Standardization of methods, including harmonized residue-testing protocols and AMR panels, to enable pooled analyses;
- Inclusion of eggs, offal, and non-ruminant species, which are under-represented in current evidence;
- Molecular epidemiology to characterize resistance genes and mobile genetic elements; and

Operationalization of One Health study designs that concurrently collect and analyze animal, food, human, and environmental data to better elucidate antimicrobial transmission pathways.

Conclusion

This systematic review demonstrates a high burden of antimicrobial residues and resistant bacteria in animal-source foods in Sokoto State, Nigeria, reflecting widespread antimicrobial use and weak regulatory oversight. The synthesis of findings have indicated serious implications for the safety of food system, public health, and well-being. Authorities need to strengthen regulation and its enforcement, and antimicrobial stewardship within a One Health framework to protect consumers and handlers, support nutritional security, and contain the spread of antimicrobial resistance.

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