Antimicrobial use and antimicrobial resistance in the poultry value chain in Zimbabwe: A review

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SUMMARY

Antimicrobial resistance in poultry production is currently a serious concern. The overuse or abuse of antimicrobials, along with inadequate hygiene in the poultry production chain, has increasedantimicrobial resistance of zoonotic bacteria, which are widely transferred through the handling and ingestion of poultry products. These bacteria represent a major threat to the environment and human health, leading to negative economic consequences. This review focused on antimicrobial usage and resistance in Zimbabwe poultry value chain. The review explored research studies published between 2000 to 2023. Searching tools included PubMed, Google Scholar, Web of Science, and African Journal Online databases. Thirteen papers out of 11508 were retained for this review, two on antibiotics use and 11 on antimicrobial resistance in poultry, with chickens being the most researched, followed by ducks, geese, and turkeys. Tetracyclines were the most used antibiotics in Zimbabwe, followed by sulfonamides, fluoroquinolones, and penicillins. *Escherichia coli* was the most common bacterium isolated, followed by *Salmonella* species, *Clostridium difficile*, and *Campylobacter*. All *E. coli* isolates were resistant to tetracycline, cefotaxime, aztreonam, cefpodoxime, and piperacillin-tazobactam. Also, all *C. difficile* isolates were resistant to gentamycin, cefotaxime, ciprofloxacin, norfloxacin, and nalidixic acid. *Salmonella* and *Campylobacter* bacteria were the least resistant. Surveillance of antimicrobial use and resistance in Zimbabwe is suboptimal, the overall picture shows an acceleration in resistance rates due to the misuse of antimicrobials.

Keywords: antimicrobial use, antimicrobial resistance, poultry, Zimbabwe

INTRODUCTION

Poultry farming is one of Zimbabwe's most common animal production industries, and chicken is the most commonly farmed species, providing the majority of the animal proteins required. Indeed, chicken farming involves low production costs and chicken consumption by people of different religious and cultural backgrounds (Pius et al., 2021). In Zimbabwe, a wide range of antimicrobial drugs are used in poultry production. They are often administered orally, to prevent and treat disease whilst also increasing growth performance, feed efficiency and productivity.

The use of antimicrobials, on the other hand, can lead to the emergence of antimicrobial resistance (AMR), and the transmission of antimicrobial-resistant bacteria (ARB) and antimicrobial-resistant genes (ARG) among poultry, environment and humans (Serwecińska, 2020). There is increasing evidence of AMR in Zimbabwe, and the situation may be dire due to widespread antimicrobial misuse in livestock production, as well as a lack of funds to develop alternatives to current antibiotics. In addition, the absence of regulation in the use of antibiotics in poultry farming, the administration of antibiotics without evidence of laboratory results, insufficient surveillance systems, and lack of updated antimicrobial use (AMU) and therapeutic strategies further aggravates these challenges.

The lack of comprehensive data on AMU and antimicrobial resistance patterns, as well as no continuing education for veterinary drug distributors and poultry owners, exacerbates Zimbabwe's AMR problem. Farmers do stock antibiotics and hire under-skilled individuals to treat chickens, hence, there is a high level of antibiotic abuse among poultry owners, and uncontrolled disposal of wastes in dumping sites (Swiswa et al., 2022b).

Due to intensive farming systems, antibiotics are still used in Zimbabwe as feed additives to enhance growth, feed efficiency, and disease resistance in chickens, to meet the increasing demand for animal proteins (Mak et al., 2022, Imam et al., 2020). The emergence and rapid spread of AMR have made disease management in poultry production extremely difficult. With a few exceptions, there is little known about the AMU, prevalence of ARB and ARGs in poultry in Zimbabwe.

Many poultry farmers believe that the benefits of antimicrobials outweigh the costs, but this depends on a variety of factors namely farm biosecurity, animal husbandry, and diet (McKernan et al., 2021). Nonetheless, the negative effects of AMR on humans (infections with resistant bacteria and occurrence of antibiotic residues in poultry products), environmental, and animal health can have long-term cultural, financial (cost of ineffective antibiotics and mortalities due to infections), food safety and environmental consequences (Hedman et al., 2020, Polianciuc et al., 2020, Samreen et al., 2021, Wu-Wu et al., 2023, Okocha et al., 2018).

Furthermore, the contamination of soil, sludge, underground water, sewage, drinking water, and plants contributes to the development and dissemination of resistant bacteria in the environment. Uncontrolled quantities of antimicrobial-containing wastes generated by poultry farmers enhance ARB and ARG selection in the surroundings, with possible spillover to people and livestock (Aslam et al., 2021, Hedman et al., 2020). Despite these statistics, Zimbabwe lacks comprehensive data on AMU and AMR in poultry and farm settings. The purpose of this review was to identify trends and patterns in the use of antimicrobial drugs, the prevalence of AMR bacteria, and the genes involved in the poultry value chain in Zimbabwe, as well as to highlight knowledge gaps and methodological considerations.

METHODOLOGY

Data were collected by reviewing peer-reviewed articles from electronic databases such as PubMed, Google Scholar, and Web of Science. Google Scholar was the most effective search engine used as it has a wide coverage of articles from libraries/publishers that include Elsevier, Springer, and African Journals Online. The focus was on antimicrobial use and antimicrobial resistance in poultry in Zimbabwe. Abstracts, full-length research articles, and review papers written in English were all considered. Combinations of search terms used for data sourcing were (antimicrobial usage OR antimicrobial use OR antibiotic use OR antibiotic usage OR antimicrobial resistance OR antimicrobial resistant OR antibiotic resistance OR antibiotic resistant OR multi-resistant OR multidrug-resistant) AND (poultry OR chickens OR hens OR ducks OR turkey OR birds) AND “Zimbabwe”.

To determine eligibility, full versions of articles that might apply were ascertained. These were then considered and analyzed for inclusion. The data was gathered out of each publication separately and entered into a harmonized Table in MS Word. We extracted information from the text, tables, and figures. The articles were evaluated to extract information on the antimicrobial use and prevalence of ARB and ARGs.

All articles found were then evaluated based on the inclusion criteria, which were studies on AMU and AMR in poultry in Zimbabwe, and these articles had to be written in English and published in a peer-reviewed journal. All studies published as editorials, letters, commentary, reviews, book chapters, case series, or case reports, as well as studies with no full text, were excluded from this study. EndNote Edition Version 7 was used to download all of the bibliographical details of selected articles. The duplicate studies were removed and the rest of the articles were screened by titles and abstracts based on the inclusion and exclusion criteria. Negotiations were used by the researchers to settle their disagreements. Alternatively, another researcher was consulted to rule out the exclusion of a specific study. The overall resistance rates for each antibiotic were calculated and tabulated.

RESULTS

The initial search resulted in a total of studies (n =11508). Studies (n =29) were duplicated. Following their removal, the titles of studies (n = 11479) were reviewed, with 11461 out of 11479 (99.67%) covering poultry AMU and AMR studies conducted in other countries. The abstracts and full text of 37 studies were examined, and 15 irrelevant studies were eliminated. Finally, based on inclusion and exclusion criteria, 13 studies meeting the criteria were selected for further analysis. Figure 1 depicts the process of searching for and selecting studies.

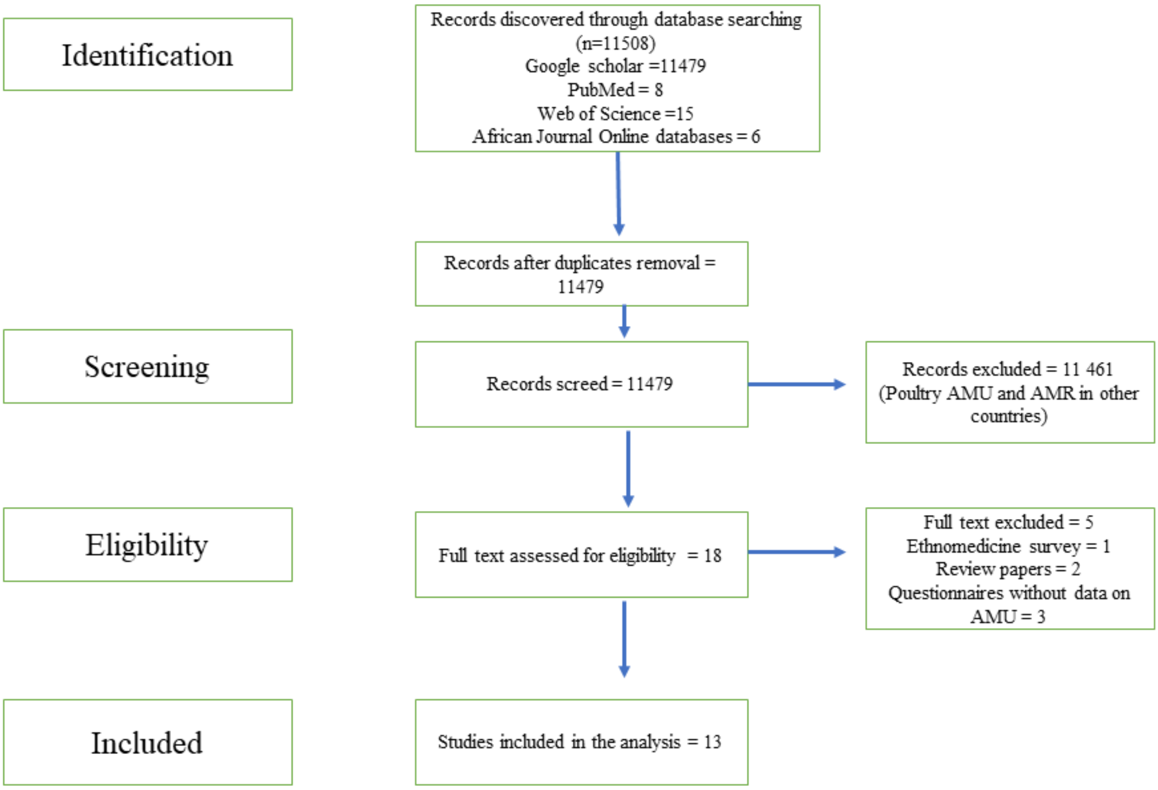

Figure 1 A flow diagram showing article selection and inclusion in this study

Antibiotic use in poultry production in Zimbabwe

A report by Swiswa et al. (2022b) indicated that tetracyclines are the most consumed antibiotics in the animal sector (Table 1). There have been limited studies to quantify the use of antibiotics at the farm level in Zimbabwe, as was done in the poultry sector through a collaborative survey (Swiswa et al., 2022a).

Table 1: Zimbabwe antibiotics consumption from 2017 to 2018

Antibiotic class	Quantity consumed (kg)
Cephalosporins	5
Macrolides	614
Quinolones	123
Penicillins	1060
Sulfonamides	1945
Tetracyclines	5846
Aminoglycosides	221
Fluoroquinolones	1441
Glycopeptides	1000
Polypeptides	184

This data was adapted from (Swiswa et al., 2022b).

This survey also revealed that tetracyclines were the most used antibiotics in poultry production, which reinforces consumption data reported by the MCAZ (Swiswa et al., 2022a Isolates of *C. difficule* from chicken faecal samples were 100% resistant to cefotaxime, gentamycin, ciprofloxacin, nalidixic acid and norfloxacin (Simango, 2006; Simango and Mwakurudza, 2008).). Feed producers in Zimbabwe use bacitracin as an antibiotic growth promoter. Bacitracin is known to have activity against *Clostridium* spp in the gastrointestinal tract and it might therefore be contributing to the development of resistance in *Clostridium* spp.

Antibiotic Resistance in the Poultry Value Chain in Zimbabwe

Most studies on antibiotic resistance in the poultry value chain in Zimbabwe were conducted on chickens, ducks, geese, and turkeys from various farming systems (Table 2). Table 2 summarises bacteriological profiles and antibiotic susceptibility patterns in the poultry value chain in Zimbabwe. *Clostridium difficile*, *E. coli*, *Salmonella* spp., *Campylobacter* spp., and other microorganisms isolated in Zimbabwe and their antimicrobial susceptibility profile were found in the searched databases. According to a study by Saidi *et al*. (2013), 103 avian pathogenic *E. coli* isolates were subjected to antibiotic susceptibility testing using the disc diffusion method and it was found that all these isolates were resistant to cloxacillin, tetracycline and bacitracin. The same *E. coli* isolates also showed varied resistance rates to ampicillin (94.1%) and gentamycin (2.9%) (Saidi et al., 2013). However; all the *E. coli* isolates were susceptible to ciprofloxacin and showed a 97.1% susceptibility to gentamycin (Saidi et al., 2013). Also, all isolates showed multidrug resistance i.e. resistance to 3 or more antibiotics (Saidi et al., 2013).

In another study by Siwela *et al*. (2007), fresh faeces were collected from a free-range chicken farm, a commercial chicken farm and a commercial ostrich farm, all located around Bulawayo City in Zimbabwe. The antibiotic resistance profile, of *E. coli*, *Enterococcus faecalis* and *Pseudomonas* spp. against ampicillin, chloramphenicol, oxytetracycline, sulfonamide, streptomycin and tetracycline, was determined. When comparing isolates from free-range chickens to those from commercial farms, it was discovered that the latter had generally higher levels of resistance to streptomycin, tetracycline, and oxytetracycline (Siwela et al., 2007). Takawira et al. (2022) also isolated 21 *E. coli* isolates from ducks and chicken, and they discovered that all of the isolates were resistant to tetracycline, cefotaxime, ciprofloxacin, nalidixic acid, cefpodoxime, and ampicillin after testing the antimicrobial susceptibility of the isolates. However, different levels of resistance to ampicillin, gentamycin, ciprofloxacin, nalidixic acid, neomycin, bacitracin, cloxacillin, and chloramphenicol were found in all *E. coli* isolates from ducks, geese, and turkeys (Dube and Mbanga, 2018). In an earlier study, Mbanga et al. (2016) isolated extended-spectrum beta-lactamase-producing *E. coli* from chicken meat in Bulawayo, 59 isolates of *E. coli* were tested against antibiotics and were all resistant to every tested antibiotic including aztreonam, cefotaxime, cefpodoxime, and piperacillin-tazobactam.

Makaya et al. (2012) investigated the antibiotic sensitivity characteristics of *Salmonella* spp. isolated from chickens reared on large-scale commercial, small-scale commercial, and rural free-range farms in Zimbabwe and reported that approximately 53 out of 206 (26%) *S. enteritidis* isolates were resistant to one or more antibiotics (Table 2). Tetracycline resistance was the most common in 34 out of 53 (64 %) followed by amoxicillin resistance in 19 out of 53 (36%) with no resistance detected for furazolidone, neomycin, or trimethoprim-sulfamethoxazole.

Furthermore, *Clostridium difficile* isolated from broiler chicken faecal matter and soils collected from cages and areas around marketplaces in Zimbabwe were all susceptible to metronidazole, vancomycin, doxycycline, chloramphenicol, and tetracycline (Simango and Mwakurudza, 2008). Erythromycin, co-trimoxazole, and ampicillin were all effective against more than 70% of the isolates. However, all the isolates were resistant to Cefotaxime, gentamicin, ciprofloxacin, norfloxacin, and nalidixic acid (Simango and Mwakurudza, 2008). Simango, (2006) isolated toxigenic *C. difficile* from the soil, free-range chicken faeces, and water samples and found that they were all susceptible to metronidazole, vancomycin, doxycycline, chloramphenicol, and tetracycline, but resistant to cefotaxime, gentamicin, ciprofloxacin, norfloxacin, and nalidixic acid.

Berger et al. (2020) discovered that all *C. difficile* isolates from chicken were susceptible to metronidazole, vancomycin, and rifampicin, with one isolate resistant to chloramphenicol and eleven isolates resistant to moxifloxacin (Figure 1). These findings indicate that chicken appears to be an important source or reservoir of *C. difficile*, which can spread the disease to the general public by eating infected poultry products and can also contaminate the environment around marketing locations.

Table 2 presents a summary of published data on antimicrobial resistance (AMR) in poultry in Zimbabwe. The table lists the antibiotics used and the bacterial isolates found in various poultry species and poultry products. The data was collected from several studies conducted in Zimbabwe. The bacterial isolates identified include *Clostridium difficile*, *E. coli*, *Salmonella* spp., *Campylobacter* spp., and others. Among the antibiotics used, sulfonamides and tetracyclines were the most commonly used antibiotics in poultry production, and the table shows that these antibiotics were associated with the highest number of bacterial isolates. The table also indicates that some antibiotics, such as metronidazole and vancomycin, were not detected in any of the samples tested.

Table 2: Bacteria isolates and their phenotypic antibiotic resistance in poultry and poultry products in Zimbabwe.

Study	**Location**	**Year of Sampling**	**Poultry spp**	**Bacterial spp**	**Test Method/ Criteria of Interpretation**	**AMR data**	**Ref.**
1	Rural area northeast of Harare	Not provided	Chicken	*C. difficile*	Disc diffusion/ Not Provided	Met (0/11), Van (0/11), Dox (0/11), Tet (0/11), Gen (11/11), Cef (11/11), Cip (11/11), Nor (11/11), Nal (11/11)	Simango, 2006
2	Countrywide	2003-2005	Chicken	*Salmonella* spp	Disc diffusion/ CLSI (2009)	Tet (19/206), Ery (5/206), Amp (0/206), Amo (14/206), Enro (7/206), Fura (0/206), Kan (8/206), Neo (0/206), SXT (0/206)	Makaya et al., 2012
3	Harare	Not provided	Chicken	*C. difficile*	Disc diffusion/ Not Provided	Met (0/29), Van (0/29), Clar (0/29), Dox (0/29) Tet (0/29), Ery (28/29), CoT (26/29), Amp (22/29), Clin (2/29), Gen (29/29), Cef (29/29), Cip (29/29), Nor (29/29), Nal (29/29)	Simango and Mwakurudza, 2008
4	Harare	2009-2010	Chicken	*Campylobacter* spp	Disc diffusion/ NCCLS (2000)	Tet (7//83), Ery (0/83), CoT (68/83), Amp (24/83), Gen (0/83), Cip (11/83), Nor (11/83), Chlor (11/83)	Simango et al., 2013
5	Harare	Jul 2012-Jan 2023	Chicken	*E. coli*	Disc diffusion/ CLSI M100-S17 (2007)	Tet (103/103), Amp (97/103), Gen (1/103), Cip (0/103), Neo (56/103), Chlor (38/103), Baci (103/103), Clox (103/103),	Saidi et al., 2013
6	Bulawayo	Not provided	Chicken	*E. coli*	Kirby–Bauer Disc diffusion/ CLSI (2011)	Cef (59/59), Azt (59/59), Pip (59/59), Cefp (59/59)	Mbanga et al., 2016
7	Bulawayo	Not provided	Ducks	*E. coli*	Kirby–Bauer Disc diffusion/ CLSI (2014	Amp (56/62), Gen (3/62), Cip (62/62), Nal (6/62), Neo (37/62), Chlor (6/62), Baci (0/62), Clox (0/62)	Dube and Mbanga, 2018
			Geese	*E. coli*	Kirby–Bauer Disc diffusion/ CLSI (2014	Amp (23/29), Gen (0/29), Cip (29/29), Nal (4/29), Neo (9/29), Chlor (15/29), Baci (0/29), Clox (0/29)	
			Turkey	*E. coli*	Kirby–Bauer Disc diffusion/ CLSI (2014	Amp (0/9), Gen (7/9), Cip (9/9), Nal (4/9), Neo (7/9), Chlor (1/9), Baci (0/9), Clox (0/9)	
8	Harare	2005	Chicken	*Clostridium difficile*	Disc diffusion and epsilometry/ Not Provided	Met (0/30), Van (0/30), Mox (11/30), Clar (1/30), Rif (0/30)	Berger et al., 2020)
9	Harare and Chitungiza	2017-2019	Ducks and chicken	*E. coli*	Disc diffusion CLSI M100 (2018)	Tet (21/21), Amp (21/21), Cef (21/21), Cip (21/1), Nal (21/21), Cef (21/21)	Takawira et al., 2022

Key to Table 2: Met- Metronidazole, Van- Vancomycin, Mox- Moxifloxacin, Clar-Clarithromycin, Rif- Rifampicin, Dox-Doxycycline, Tet-Tetracycline, Ery-Erythromycin, CoT-Cotrimoxazole, Amp-Ampicillin, Clin-Clindamycin, Gen-Gentamicin, Cef-Cefotaxime, Cip-Ciprofloxacin, Nor-Norfloxacin, Nal-Nalidixic acid, Azt-Aztreonam, Cefp-Cefpodoxime, Pip-Piperacillin-tazobactam, Enr-Enrofloxacin (Baytril), Fur-Furazolidone, Kan-Kanamycin, Neo-Neomycin, Sxt-trimethoprim/sulfamethoxazole, Amo-Amoxicillin, Bac-Bacitracin, Clox-Cloxacillin, Chlor-Chloramphenicol, (AST-Antibiotic susceptibility testing, MHA-Muller Hinton agar, CLSI- Clinical Laboratory Standards Institute, NCCLS -National Committee for Clinical Laboratory Standards. The AMR data is represented as number of resistant strains over number of isolates tested.

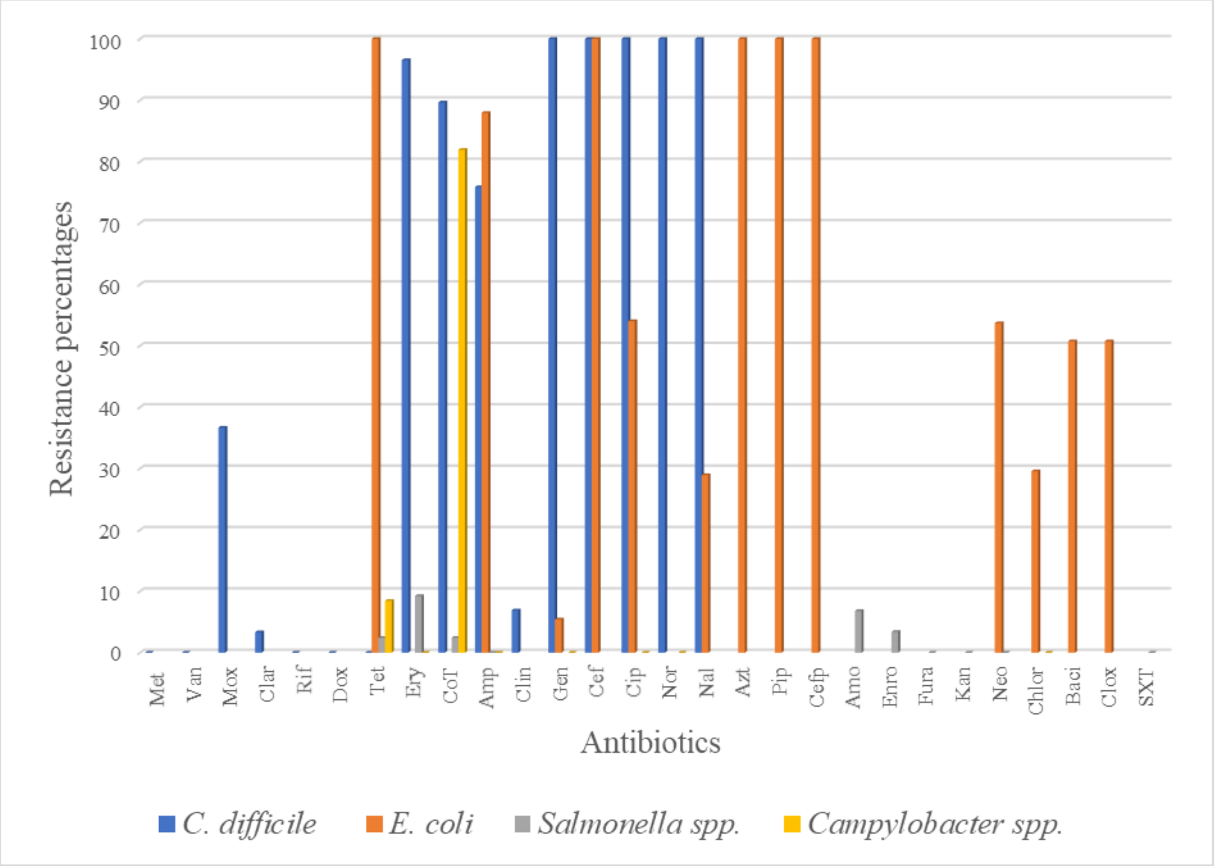

Figure 2: Antibiotic resistance rates in isolated bacteria from Zimbabwean poultry.

Antimicrobial resistance genes from poultry value chain in Zimbabwe.

A few studies have been carried out to detect bacterial antimicrobial resistance genes in Zimbabwe. In a retrospective one-health study conducted by Mashe et al. (2021), 245 non-typhoidal *Salmonella* isolates were examined. These isolates were collected from chickens and humans between 2016 and 2020. An in-depth analysis of the *S. kentucky* serovars revealed that the majority of isolates from both chicken and human samples carried antibiotic resistance genes, namely *bla*$_{CTX\text{-}M\text{-}14.1}$ (89.2%) and *fosA3* (89.2%).

Additionally, genetic mutations in the *gyrA* and *parC* genes were present in 97.3% of the samples. In a study by Mbanga et al. (2016), it was discovered that retail chicken meat contaminated with ESBL-producing *E. coli* isolates contained either the *bla*$_{TEM}$, *bla*$_{SHV}$, and *bla*$_{CTX\text{-}M}$ genes or a combination of these genes. Notably, the *bla*$_{OXA}$ gene was absent in some of the *E. coli* isolates tested (Mbanga et al., 2016). Out of the *E. coli* isolates tested, 28 (23.3%) were positive for the *bla*$_{TEM}$ gene, while 6 (5%) and 5 (4.2%) were positive for *bla*$_{CTX\text{-}M}$ and *bla*$_{SHV}$, respectively (Mbanga et al., 2016). Takawira et al. (2022) performed whole genome sequencing on *E. coli* isolates from broilers, backyard chickens, and duck cloacal swabs and discovered the cefotaximase-Munich-14 (*CTX-M-14*) or *CTX-M-79* resistant genes. Furthermore, *qnrB19* and *qnrS1* genes were identified as plasmid-mediated quinolone-resistant determinants, and one *E. coli* isolate from broilers contained a mobile colistin resistance gene (*mcr-1*) (Takawira et al., 2022).

Table 3: Antimicrobial resistance genes in poultry in Zimbabwe.

Study	Location	Poultry spp	Year of Sampling	Bacterial spp	Genotypic resistance data (genes detected/number of isolates tested)	Reference
1	Bulawayo	Chicken	Not provided	*E. coli*	bla_{CTX-M} (6/120) bla_{SHV} (5/120) bla_{TEM} (28/120) bla_{CTX-M} & *TEM* (5/120) bla_{SHV} & *TEM* (2/120) bla_{CTX-M} & *TEM* & *SHV* (1/120)	Mbanga et al.,2016
2	Harare	Chicken	2016-2020	*S. Kentuky*	$bla_{CTX-M-14}$ (33/37) *fosA3* (33/37)	Mashe et al., 2021
3	Harare	Chicken	2017-2019	*E. coli*	$bla_{CTX-M-14}$ (6/21) $bla_{CTX-M-15}$ (1/21) $bla_{CTX-M-55}$ (2/21) $bla_{CTX-M-79}$ &*TEM* & *OXA* (2/21) *qnrS19* (13/21), *qnrB1* (12/21), *qnrD1* (2/21) *mcr-1* (1/21)	Takawira et al., 2022

Key: spp-species, bla-beta-lactamase, CTX-M-cefotaximase-Munich, SHV-sulfhydryl variable, TEM-temoneira, *qnr*- quinolone resistance, *mcr-1*-mobile colistin resistance, *fos*-fosfomycin

DISCUSSION

Antimicrobial resistance (AMR) is linked to excessive antimicrobial use (AMU) in animal production, which is a major driver in the development and promulgation of AMR (Burow et al., 2014, Bell et al., 2014, van Boeckel et al., 2014). The paltry number of publications on AMU in poultry shows that Zimbabwe has a long way to go concerning monitoring AMU in animal production. Zimbabwe is not alone in this predicament as other studies on AMU in Africa and other low to middle-income countries have also concluded that there is a large deficit of data on AMU in food animals in these countries (Mshana et al., 2021, Cuong et al., 2018).

The first study on AMU in Zimbabwe was a desk review report using data from the Medicines Control Authority of Zimbabwe but the data was not specific to animal species, as it was based on import data of drugs (Swiswa et al., 2022a).

The second pilot survey by Swiswa et al. (2022b), measured AMR in poultry at the farm/patient level and reported that tetracyclines were the most consumed antibiotics in Zimbabwe from 2017 - 2018, followed by sulfonamides, fluoroquinolones, and cephalosporins (Table 1). Swiswa et al. (2022a) found that amoxicillin, colistin, doxycycline, enrofloxacin, fosfomycin, furaltodone, neomycin, oxytetracycline, streptomycin, sulfadimidine, sulfadiazine, sulfadoxine, sulfamethoxazole, and sulfaquinoxaline were commonly used by broiler farmers in Zimbabwe. A similar study conducted on selected poultry farms in Ghana reported that tetracyclines, sulfonamides, and penicillins were the most commonly used antibiotics (Boamah et al., 2016).

AMR testing in reviewed articles used the disc diffusion method and none determined the MICs of the drugs. Six of the ten studies used international standards to interpret antimicrobial susceptibility data with five using Clinical and Laboratory Standards Institute (CLSI) guidelines whilst one study used the National Committee for Clinical Laboratory Standards (NCCLS). In the other studies, information on the interpretation criteria was entirely omitted limiting comparison across the studies. Fifty per cent of the studies did not provide the year of sampling making trend analysis difficult.

Harmonization of the test methods is important for the comparison of data across studies. Most of the studies (70%) were carried out in Harare and Bulawayo and their surrounding areas. This means that the studies do not show the complete picture of the AMR burden in the poultry value chain in the country. None of the studies had data on treatment failure due to AMR. There is a need to establish relationships between phenotypic data (inhibition zones, MICs) and chances of treatment success (Nhung et al., 2016).

Two of the studies reported a 100% prevalence of tetracycline resistance in *E. coli* (Saidi et al., 2013; Mbanga et al., 2016) and correlated with findings from studies on antimicrobial use as tetracyclines were the most widely consumed antibiotics in animal production (Swiswa et al., 2022b). *E. coli* has been extensively used to monitor AMR in food animals since it is ubiquitous in the gastrointestinal tracts of warm-blooded animals (EFSA, 2018, Nhung et al., 2016). All *E. coli* isolates were also resistant to cefotaxime, aztreonam, piperacillin-tazobactam and cefpodoxime (Mbanga et al., 2016, Takawira et al., 2022). This shows that AMR now poses a serious health threat in both veterinary and human medicine in the country.

Genotypic resistance studies were done on samples collected in Harare and Bulawayo and areas close to the two cities. There is, therefore, a need to collect genotypic resistance data in other provinces to get a complete picture of the prevalence of resistance in the country. Two of the studies which collected genotypic resistant data were done on *E. coli* and one was on *S. Kentucky*. The presence of resistant genes in *E. coli* strains which were reported in the two studies validates the massive phenotypic resistance which was observed on *E. coli* isolates.

Some *E. coli* strains hosted by poultry have the potential to transmit AMR genes to humans (Kheiri and Akhtari, 2016; Overdevest et al., 2011). Therefore, there is a need for collaboration between researchers working on human, environmental and veterinary samples in a one health approach to ascertain whether some resistant *E. coli* strains causing infections in humans are coming from animals or the environment.

The collaboration may not only contributes in reduction of a gap in knowledge on genotypic resistance but also on other important zoonotic and food-borne pathogens such as *Campylobacter*, *Clostridia* spp and other *Salmonella* strains. Genotypic resistance studies showed that quite several antimicrobial resistance genes were present in poultry in Zimbabwe (Table 3), suggesting that, the use of antibiotics in poultry production is contributing to the emergence and spread of antibiotic-resistant bacteria. Of note is the discovery of cefotaximase-Munich-14 (*CTX-M-14*) or *CTX-M-79* resistant genes, plasmid-mediated quinolone-resistant determinants *qnrB19* and *qnrS1* and Extended-Spectrum Beta-Lactamases (ESBL) genes from *E. coli* isolated from poultry samples (Takawira et al., 2022; Mbanga et al, 2016). *CTX-M-14* genes are responsible for conferring resistance to a broad range of antibiotics, including third-generation cephalosporins, *qnrB19* and *qnrS1* confer quinolone resistance whilst ESBLs are enzymes produced by bacteria that confer resistance to many beta-lactam antibiotics. The ESBL-producing *E. coli* isolates from retail chicken meat contained either the bla_{TEM}, bla_{SHV}, and $bla_{CTX\text{-}M}$ genes or a combination of these genes (Mbanga et al, 2016). Moreover, the Takawira et al. 2022 study identified a mobile colistin resistance gene (*mcr-1*) in one of the *E. coli* isolates from broilers.

Colistin is considered a last-resort antibiotic for treating infections caused by antibiotic-resistant bacteria. The presence of these various resistant genes in *E. coli* isolates is particularly worrisome, as *E. coli* is a common pathogen in both humans and animals. The results from these studies highlight the need for appropriate measures to control the spread of antimicrobial-resistant bacteria and the importance of prudent AMU in animal production.

The presence of antimicrobial-resistant bacteria and antibiotic-resistance genes in poultry and poultry products in Zimbabwe is a major public health concern, as poultry can act as ARB and ARG reservoirs and can transmit AMR to humans through handling and consumption. However, because the number and type of antibiotics used were not standardized, these findings may not provide a clear indication of the resistance status or pattern of the isolated bacteria poultry in Zimbabwe.

A One Health approach, as well as relevant mitigation strategies, should be designed, and implemented. Few studies have been conducted in Zimbabwe due to a lack of financial support for the One Health program and a lack of rigorous active surveillance programs. This suggests that, concerted efforts are needed to limit the spread of AMR in zoonotic bacteria, including the implementation of antimicrobial stewardship, evidence-based control strategies, the development of novel antimicrobials, the development of innovative antibiotic alternatives feed additives such as phytobiotics and immunobiotics, improved biosecurity and good animal husbandry, improvements in poultry production chain practices, and a reduction in the number of antibiotics used among others.

Moreover, AMR surveillance programs must be improved in terms of better standardization and the use of quick sequence-based approaches in the regular surveillance of AMR. These can be implemented simultaneously with intensification of research to facilitate a greater understanding on the transmission dynamics and inform the development of effective preventive strategies.

CONFLICT OF INTEREST

The authors declare that they are not aware of any competing financial interests or personal relationships that might influence the work described in this study.

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