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Antibiotic Use in Poultry Production and Its Effects on Bacterial Resistance

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Abstract

A surge in the development and spread of antibiotic resistance has become a major cause for concern. Over the past few decades, no major new types of antibiotics have been produced and almost all known antibiotics are increasingly losing their activity against pathogenic microorganisms. The levels of multi-drug resistant bacteria have also increased. It is known that worldwide, more than 60% of all antibiotics that are produced find their use in animal production for both therapeutic and non-therapeutic purposes. The use of antimicrobial agents in animal husbandry has been linked to the development and spread of resistant bacteria. Poultry products are among the highest consumed products worldwide but a lot of essential antibiotics are employed during poultry production in several countries; threatening the safety of such products (through antimicrobial residues) and the increased possibility of development and spread of microbial resistance in poultry settings. This chapter documents some of the studies on antibiotic usage in poultry farming; with specific focus on some selected bacterial species, their economic importance to poultry farming and reports of resistances of isolated species from poultry settings (farms and poultry products) to essential antibiotics.

Keywords: bacteria, antibiotic resistance, antibiotics, antimicrobials, poultry

1. Introduction

Antibiotic resistance (AR) which is defined as the ability of an organism to resist the killing effects of an antibiotic to which it was normally susceptible [1] and it has become an issue of global interest [2]. This microbial resistance is not a new phenomenon since all microorganisms

have an inherent capacity to resist some antibiotics [3]. However, the rapid surge in the development and spread of AR is the main cause for concern [4]. In recent years, enough evidence highlighting a link between excessive use of antimicrobial agents and antimicrobial resistance from animals as a contributing factor to the overall burden of AR has emerged [5]. The extent of usage is expected to increase markedly over coming years due to intensification of farming practices in most of the developing countries [6]. The main reasons for the use of antibiotics in food-producing animals include prevention of infections, treatment of infections, promotion of growth and improvement in production in the farm animals [7, 8].

Poultry is one of the most widespread food industries worldwide. Chicken is the most commonly farmed species, with over 90 billion tons of chicken meat produced per year [9]. A large diversity of antimicrobials, are used to raise poultry in most countries [10–12]. A large number of such antimicrobials are considered to be essential in human medicine [13, 14]. The indiscriminate use of such essential antimicrobials in animal production is likely to accelerate the development of AR in pathogens, as well as in commensal organisms. This would result in treatment failures, economic losses and could act as source of gene pool for transmission to humans. In addition, there are also human health concerns about the presence of antimicrobial residues in meat [15, 16], eggs [17] and other animal products [18, 19].

Generally, when an antibiotic is used in any setting, it eliminates the susceptible bacterial strains leaving behind those with traits that can resist the drug. These resistant bacteria then multiply and become the dominating population and as such, are able to transfer (both horizontally and vertically) the genes responsible for their resistance to other bacteria [1, 20]. Resistant bacteria can be transferred from poultry products to humans via consuming or handling meat contaminated with pathogens [21]. Once these pathogens are in the human system, they could colonize the intestines and the resistant genes could be shared or transferred to the endogenous intestinal flora, jeopardizing future treatments of infections caused by such organisms [5, 22–24].

2. Use of antibiotic in animal production

Antimicrobials' use in animal production dates as far back as the 1910 when due to shortage of meat products, workers carried out protests and riots across America [25]. Scientists at that time started looking for means of producing more meat at relatively cheaper costs; resulting in the use of antibiotics and other antimicrobial agents [26]. With the global threat of antibiotic resistance and increasing treatment failures, the non-therapeutic use of antibiotics in animal production has been banned in some countries [8, 27–29]. Sweden is known to be the first country to ban the use of antimicrobials for non-therapeutic purposes between 1986 (for growth promotion) and 1988 (for prophylaxis) [27]. This move was followed by Denmark, The Netherlands, United Kingdom and other European Union countries [27]. These countries also moved a step further and banned the use of all essential antibiotics as prophylactic agents in 2011 [30].

Several other countries have withdrawn the use of some classes of antibiotics or set up structures that regulate the use of selected antibiotics in animal production [29]. Despite these

developments, it is currently estimated that over 60% of all antibiotics produced are used in livestock production, including poultry [6, 31].

The use of antibiotics in poultry and livestock production is favorable to farmers and the economy as well because it has generally improved poultry performance effectively and economically but at the same time, the likely dissemination of antibiotic resistant strains of pathogenic and non-pathogenic organisms into the environment and their further transmission to humans via the food chain could also lead to serious consequences on public health [32].

3. Antimicrobial resistance

Bacteria counteract the actions of antibiotics by four well-known mechanisms, namely; enzyme modification, alteration in target binding sites, efflux activity and decreased permeability of bacterial membrane [33]. This expression of resistance towards antibiotics by bacteria could either be intrinsic or acquired. Intrinsic resistance is due to inherent properties within the bacteria chromosome such as mutations in genes and chromosomally inducible enzyme production [34], whereas acquired resistance could be due to the transmission of resistance genes from the environment and/or horizontally transfer from other bacteria [35, 36].

4. Antibiotic resistance of some selected organisms in poultry

4.1. *Staphylococcus* species

The bacterial genus *Staphylococcus* is a Gram-positive cocci and a facultative anaerobe which appears in clusters when viewed under the microscope [37]. They are etiological agents of staphylococcosis, pododermatitis (bumblefoot) and septicaemia which affect mostly chicken and turkeys. Coagulase-negative species have also been implicated in human and animal infections [38, 39].

β -lactams were considered the first line of drugs for treatment of staphylococcal infections but due to emergence of high level of resistance to these and other drugs, there are currently very few drugs available for treatment of these infections [40]. Methicillin resistant *Staphylococcus aureus* (MRSA), now known as a superbug, is resistant to almost every available antibiotic used against *Staphylococcus* [41].

A study to detect the presence of MRSA in broilers, turkeys and the surrounding air in Germany reported the prevalence of MRSA in air as high as 77% in broilers compared to 54% in Turkeys. Ten different spa types were identified with spa type t011 and clonal complex (CC) 398 being the most prevalent. It was also found that for every farm, the same sequence types were present in both the birds and the environment [42]. This pattern of resistance was also reported in India with 1.6% of staphylococcal isolates containing mecA resistant gene [43].

In Africa, studies carried out in Ghana and Nigeria have shown that livestock-associated *Staphylococci* are susceptible to amoxicillin/clavulanic acid, amikacin, ciprofloxacin, gentamycin

and cephalexin [39, 44], whereas in the US, most of the staphylococcal isolates were susceptible to rifampin, cotrimoxazole, gentamycin, vancomycin and chloramphenicol [45, 46]. It is worth noting that most of these organisms showed a high level of resistance to oxacillin and tetracycline, which would be disastrous if these oxacillin-resistant strains are transferred to humans [39, 44, 45].

4.2. *Pseudomonas* species

Pseudomonas is a genus of Gram-negative, aerobic bacteria that belongs to the family Pseudomonadaceae [47]. The genus *Pseudomonas* is ubiquitous in soil, water and on plants. It consists of 191 subspecies belonging to species groups including *P. fluorescens*, *P. pertucingena*, *P. aeruginosa*, *P. chlororaphis*, *P. putida*, *P. stutzeri* and *P. syringae*. Pseudomoniasis, which is an opportunistic *P. aeruginosa* infection, is common in poultry birds like chickens, turkeys, ducks, geese and ostriches where infections in eggs destroy embryos [48].

P. aeruginosa causes respiratory infection, sinusitis, keratitis/keratoconjunctivitis and septicemia and responsible for pyogenic infections, septicemia, endocarditis and lameness along with many diverse diseases [49]. Infections may occur through skin wounds, contaminated vaccines and antibiotic solutions or needles used for injection. The disease may be systemic, affecting multiple organs and tissues or localized in tissues as infraorbital sinus or air sacs producing swelling of the head, wattles, sinuses and joints in poultry birds. *P. aeruginosa* has been isolated from many poultry farms and birds worldwide [49].

A study carried out in Ghana show that *P. aeruginosa* isolated from poultry litter were all susceptible to levofloxacin in the range of 20–100% and nearly 75% demonstrated intermediate susceptibility to aztreonam. The organisms showed resistance to cephalosporins, carbapenems, penicillins, quinolones, monobactam and aminoglycoside. Metallo β -Lactamase encoding genes (*blaIMP*, *blaVIM*) were not detected in any of the isolates but the class 1 integron which is known to carry multiple antibiotic resistant genes were detected in 89.4% of the multi-drug resistant strains [50]. This is contrary to a report by Zhang and his Colleagues [51], who identified the *blaVIM* gene in *P. aeruginosa* and *P. putida* from chicken that resembled corresponding regions in clinical isolates of *P. aeruginosa*. These isolates were resistant to all β -lactam antibiotics tested, including meropenem, imipenem, aztreonam, and ceftazidime [33, 51].

Another study in Nigeria reported that the *P. aeruginosa* isolates were highly resistant to β -lactams, tetracycline, tobramycin, nitrofurantoin and sulfamethoxazole-trimethoprim, while ofloxacin, imipenem and ertapenem were highly effective against the bacterial pathogens [52].

In Pakistan, a study which investigated the causative agents for necropsy in chicken, recorded a 28% prevalence for *P. aeruginosa*. These isolates were found to be 100% resistant towards ceftriaxone, meropenem, ciprofloxacin, erythromycin and colistin, while 60% sensitivity was observed against ampicillin sulbactam, ceftazidime, cefoperazone and rifampicin. Isolates exhibited variable multidrug resistance patterns to other antibiotics [53].

4.3. *Escherichia* species

Escherichia coli is a Gram-negative bacterium that has been known for ages to easily and frequently exchange genetic information through horizontal gene transfer with other related

bacteria. Hence, it may exhibit characteristics based on the source of isolation. *E. coli* is a commensal organism living in the intestines of both humans and animals. However, some strains have been reported to cause gastrointestinal illnesses [54]. Tetracycline which is commonly used in poultry has been reported to be one of the drugs bacteria are most resistant to. There is a reported tetracycline resistance in poultry even without the administration of this antibiotic [21].

A study carried out on fecal isolates of *E. coli* in the Netherlands showed that there is a high level of multidrug resistance occurring in broilers, turkeys while majority of those from laying hens were susceptible. It was observed that the isolates from birds had high rates of resistance to amoxycillin alone and others had resistance to amoxicillin as well as oxytetracycline, streptomycin, sulfamethoxazole and trimethoprim. [55].

E. coli had a prevalence of 46.98% among the other bacteria isolated in Ghana. All isolates showed some degree of resistance to ceftriaxone (1.34%), cefotaxime (0.67%), gentamycin (2.01%), cotrimoxazole (1.34%), tetracycline (2.01%) and ampicillin (3.36%) [56]. Resistant genes have been found in *E. coli* isolates from Nigeria and these include bla-TEM (85%), sul2 (67%), sul3 (17%), aadA (65%), strA (70%), strB (61%), catA1 (25%), cmlA1 (13%), tetA (21%) and tetB (17%) which conveyed resistance to the following antibiotics; tetracycline (81%), sulfamethoxazole (67%), streptomycin (56%), trimethoprim (47%), ciprofloxacin (42%), ampicillin (36%), spectinomycin (28%), nalidixic acid (25%), chloramphenicol (22%), neomycin (14%) gentamicin (8%). In this study the isolates were susceptible to amoxicillin-clavulanate, ceftiofur, cefotaxime, colistin, florfenicol and apramycin. Class 1 and 2 integrons were found in five (14%) and six (17%) isolates, respectively, while one isolate contained both classes of integrons. There is that suggestion that poultry production environments represent important reservoirs of antibiotic resistance genes such as qnrS that may spread from livestock production farms to human populations via manure and water [57].

4.4. *Salmonella* species

Salmonella spp. are Gram-negative, facultative anaerobic, non-spore forming, usually motile rods belonging to the Enterobacteriaceae family, which are found in the alimentary tract of animals [37, 58]. Fecal shedding allows *Salmonella* to be transmitted among birds in a flock. *Salmonella* spp. is widespread in poultry production. Prevalence varies considerably depending on country and type of production as well as the detection methods applied. It is known to be the etiological agent responsible for salmonellosis by *Salmonella* spp. in both humans and animals. Food-borne salmonellosis caused still occurs throughout the world [58]. The risk factors associated with *Salmonella* infections and contamination in broiler chickens include contaminated chicks, size of the farm and contaminated feed and these risk increase when feed trucks are parked near the entrance of the workers' change room and when chicken are fed with meals [59, 60]. It also depends on age of the chicken, animal health, survival of organism in the gastric barrier, diet and genetic constitution of the chicken could also affect the colonization ability of *Salmonella* spp. in poultry [61].

Pullorum disease in poultry is caused by the *S. pullorum*. Transmission of the disease in birds can be vertical (transovarian) but also occurs through direct or indirect contact with infected birds via respiratory route or fecal matter or contaminated feed, water, or litter. Antimicrobials

used to treat pullorum disease are furazolidone, gentamycin sulfate and antimetabolites (sulfadimethoxine, sulfamethazine and sulfamerazine) [62].

Salmonella spp. have increasingly been isolated from poultry with prevalence of 2.7% in Brazil and the most common isolates were *Salmonella enteritidis* (48.8%), *S. infantis* (7.6%), *S. typhimurium* (7.2%), and *S. heidelberg* (6.4%). All the isolated strains were resistant to at least one class of antimicrobial and 53.2% showed multidrug resistance to three or more classes, with streptomycin (89.2%), sulfonamides (72.4%), florfenicol (59.2%), and ampicillin (44.8%) [63].

Salmonella spp. are one of the commonest microbial contaminants in the poultry industry. In Ghana, there is high prevalence rate of 44.0% in poultry with main isolates being *S. kentucky* (18.1%), *S. nima* (12.8%), *S. muenster* (10.6%), *S. enteritidis* (10.6%) and *S. virchow* (9.6%). Resistance of these isolates to the various antibiotics were nalidixic acid (89.5%), tetracycline (80.7%), ciprofloxacin (64.9%), sulfamethazole (42.1%), trimethoprim (29.8%) and ampicillin (26.3%).

4.5. *Streptococcus* species

Streptococcus is Gram-positive bacteria. *Streptococcus gallolyticus* is a common member of the gut microbiota in animals and humans; however, being a zoonotic agent, it has been reported to cause mastitis in cattle, septicemia in pigeons, and meningitis, septicemia, and endocarditis in humans [64]. A study carried out in Japan isolated *Streptococcus gallolyticus* from pigeons with septicaemia. Most of the isolates were susceptible to vancomycin, penicillin G and ampicillin, while some were resistant to tetracycline, doxycycline and lincomycin. All the isolates were resistant to tetracycline had tet(M) and/or tet(L) and/or tet(O) genes [65].

4.6. *Campylobacter* species

Campylobacter jejuni and *Campylobacter coli* are the most prevalent disease causing species of the genus *Campylobacter*. They are mostly responsible for foodborne gastroenteritis in humans [66–68]. Campylobacteriosis is often associated with handling of raw poultry or eating of undercooked poultry meat [69]. Cross-contamination of raw poultry to other ready-to-eat foods via the cook's hands or kitchen utensils has been reported. Erythromycin is usually the drug of choice for the treatment of *Campylobacter* infections [68]. However, fluoroquinolones, gentamicin, and tetracycline are also clinically effective in treating *Campylobacter* infections when antimicrobial therapy is required [70].

Resistance of *C. jejuni* and *C. coli* isolates to fluoroquinolones, tetracycline, and erythromycin has been reported. The increased resistance is partly due to the wide use of these antimicrobials in animal husbandary, especially in poultry [71, 72].

A study carried out by Elz'bieta and his colleagues, in their quest to compare the prevalence and genetic background of antimicrobial resistance in Polish strains of *C. jejuni* and *C. coli* isolated from chicken carcasses and children reported a slight difference in resistance between human and chicken strains. The isolated *Campylobacter* strains were found to be resistant to gentamycin, tetracycline, ampicillin, ciprofloxacin and erythromycin and tet(O) gene and

mutations in the *gyrA* genes were found to be associated with the observed antibiotic resistance in the study [73].

Another study carried out in Kenya isolated thermophilic *Campylobacter* species (*C. jejuni* and *C. coli*) from feces and cloacal swabs of chicken. These isolates showed a high rate of resistance to nalidixic acid, tetracycline and ciprofloxacin of 77.4, 71.0 and 71.0%, respectively. Low resistance (25.8%) was detected for gentamicin and chloramphenicol and 61.3% of *C. jejuni* isolates exhibited multidrug resistance and 54.5% of the *C. jejuni* isolates possessed the *tet(O)* gene whereas all of *C. coli* had the *tet(A)* gene [74].

C. jejuni and *C. coli* are the predominant species of *Campylobacter* usually isolated from poultry farms. In Ghana, other species such as *Campylobacter lari*, *Campylobacter hyo-intestinalis* and *C. jejuni* sub sp. *doylei* have been isolated from poultry. These organisms have been found to be resistant to β -lactams, quinolones, aminoglycosides, erythromycin, tetracycline, chloramphenicol and trimethoprim-sulfamethoxazole and all isolated species were sensitive to imipenem [75, 76].

4.7. *Yersinia* species

It is a Gram-negative non-spore-forming rod, a psychrotrophic bacterium and able to survive and multiply at cold temperatures. Poultry meat is one of the most important sources of *Yersinia* spp. infections in humans. *Yersinia enterocolitica* is the predominant specie mostly isolated from poultry and poultry products [77]. In humans, *Y. enterocolitica* is an enteric pathogen which commonly causes acute enteritis associated with fever, bloody diarrhea and inflammation of lymph nodes. Contaminated food is one of the main sources of yersiniosis in humans [77].

Y. enterocolitica is widely distributed in nature and animals; food and environment are routinely contaminated with this organism. Major reservoir of *Y. enterocolitica* is swine. However, *Y. enterocolitica* has been frequently isolated from poultry and ready-to-eat foods [78]. A study in Iran reported a prevalence rate of *Y. enterocolitica* of 30% of among chicken meat samples [79]. *Yersinia* isolates (16%) from chicken and beef meat samples were mostly resistant to cephalotin (98%) and ampicillin (52%) [80].

Y. enterocolitica isolated from poultry raw meat and retailed meats in Poland were classified as biotype 1A and exhibited moderate ability of producing biofilms and *ystB* was the predominant virulence gene. In biofilms, a multi-system that include poor antibiotic penetration, nutrient limitation and slow growth, adaptive stress responses, and formation of persister cells are hypothesized to constitute the organisms' resistance to antibiotics [81].

4.8. *Clostridium* species

Clostridium is a genus of Gram-positive obligate anaerobic bacteria which includes several significant human pathogens. Spore of *Clostridium* normally inhabits soil and intestinal tract of animals and humans [82]. Common infections caused by *Clostridia* include botulism caused by *C. botulinum*, pseudomembranous colitis caused by *C. difficile*, cellulitis and gas gangrene

caused by *C. perfringens*, tetanus caused by *C. tetani* and fatal post-abortion infections caused by *C. sordellii* [83].

High-dose penicillin-G remains sensitive to *Clostridia* species and thus widely used to treat Clostridial infections. *Clostridia* species such as *welchii* and *tetani* respond to sulfonamides [82]. Tetracyclines, carbapenems, metronidazole, vancomycin and chloramphenicol are effective options for treatment of *Clostridia* infections [84].

C. perfringens is known to cause necrotic enteritis in poultry. Bacitracin or virginiamycin is an effective treatment option when administered in the feed or drinking water. *C. colinum* is responsible for ulcerative enteritis. Bacitracin and penicillins are the most effective drugs in the treatment and prevention of this infection [85, 86].

A study in Egypt, identified 125 isolates of *C. perfringens* from clinical cases of necrotic enteritis in broiler chickens from 35 chicken coops and the all isolates were resistant to gentamycin, streptomycin, oxolinic acid, lincomycin, erythromycin and spiramycin. Over 95% of isolates were resistant to sulfamethoxazole-trimethoprim, doxycycline, perfloxacin, colistin and neomycin. Most of the isolates were susceptible to amoxicillin, ampicillin, fosfomycin, florfenicol and cephradine [85].

Thirty strains of *C. perfringens* isolated from chickens with necrotic enteritis in Korea were found to susceptible to ampicillin, amoxicillin/clavulanic acid, cephalothin, cefepime, chloramphenicol, cefoxitin, ceftiofur, florfenicol and penicillin but resistant to gentamycin, neomycin, streptomycin, apramycin and colistin [87]. This trend of resistance was similar to that observed in 43 *C. perfringens* isolates from the ileum of 5-week old broiler chicken in Taiwan. Most of the *C. perfringens* isolates were susceptible to amoxicillin, bacitracin and enrofloxacin but resistant to erythromycin, lincomycin and chlortetracycline [88].

4.9. *Bacillus* species

Bacillus is a genus of Gram-positive, obligate aerobic or facultative anaerobic rod shaped bacteria of the phylum firmicutes. *Bacillus* spp. include both free-living non-parasitic and parasitic pathogenic species [89]. Medically significant species include *B. anthracis* which causes anthrax and *B. cereus* which causes food poisoning [90]. Other infections caused by *Bacilli* spp. include pneumonia, endocarditis, ocular and musculoskeletal infections. Antibiotics usually used for *Bacillus* infections include vancomycin, imipenem, ciprofloxacin, gentamycin, tetracycline, chloramphenicol, clindamycin and erythromycin. Most *Bacillus* spp. have been found to be resistant to broad spectrum cephalosporins and ticarcillin-clavulanate [91].

In a study involving 18 strains of *B. cereus* isolated from raw and processed poultry meat from supermarkets in Iasi county, all the isolates were found to be resistant to penicillin, amoxicillin, amoxicillin-clavulanate, colistin, cefoperazone, sulfamethizole and metronidazole but sensitive to erythromycin, cotrimoxazole, tylosin, flumequine, kanamycin, gentamycin, enrofloxacin, oxolinic acid, apramycin, tetracycline and doxacin. All *B. cereus* isolates were resistant to nearly half of tested antibiotics [92]. This pattern of resistance was also observed in 44 strains of *B. cereus* isolated from chicken and chicken products in the Jammu region of India. All isolates were resistant to penicillin G but sensitive to streptomycin. Over 60% of isolates were resistant to amoxicillin, ampicillin and carbenicillin [93].

4.10. *Mycobacterium* species

Mycobacteria are acid-fast, aerobic, nonmotile bacteria of the genus *Mycobacterium* [94]. *Mycobacteria* are widespread organisms that live in water and food sources and can colonize their hosts without showing any adverse signs and symptoms. Pathogenic mycobacterial species including *M. tuberculosis*, *M. bovis*, *M. africanum*, *M. macroti* cause tuberculosis while *M. leprae* is responsible for leprosy. *Mycobacteria* spp. are naturally resistant to penicillin and mostly susceptible to clarithromycin and rifamycin [95].

A study in Bangladesh identified three *Mycobacterium* isolates from 80 poultry droppings and all isolates were found to be resistant to rifampicin but highly susceptible to azithromycin, ciprofloxacin, streptomycin and doxycycline. One isolate was identified as multi-drug resistant [96].

4.11. *Klebsiella* species

Klebsiella is a genus of non-motile, Gram-negative, oxidase-negative, rod-shaped bacteria with a prominent polysaccharide capsule and belong to the family *Enterobacteriaceae* [97]. *Klebsiella* species are found everywhere in nature including soil, plants, insect, humans and other animals [98]. Infections caused by *Klebsiella* spp. include septicaemia, meningitis, urinary tract infections, pneumonia, diarrhea [97]. Common pathogenic *Klebsiella* in humans and animals include *K. pneumoniae*, *K. oxytoca* and *K. variicola* [99]. Antibiotics commonly used in the treatment of *Klebsiella* infections include third-generation cephalosporins, carbapenems, aminoglycosides and quinolones [100].

A study in Langa, South Africa identified 102 sub-species of *K. pneumoniae* (96 *K. ozaenae* and 6 *K. rhinoscleromatis* strains) from 17 free-range chicken samples. The isolates exhibited high level of resistance towards ampicillin (66.7%), nalidixic acid (61.8%), tetracycline (59.8%) and trimethoprim (50.0%) but highly susceptible towards gentamycin (3.9%) and ciprofloxacin (4.8%). Almost 40% of the isolates were found to be multi-drug resistant *K. pneumoniae* strains [99]. Similar trend of resistance was observed among 77 *K. pneumoniae* isolates from poultry birds in Ekiti-state, Nigeria. The isolates showed high level of resistance towards tetracycline (100%), amoxicillin (94.8%), cotrimoxazole (94.8%) and augmentin (85.7%) [98].

4.12. *Enterococcus* species

Enterococcus is a large genus of Gram-positive diplococci, lactic acid-producing bacteria of the phylum Firmicutes [101]. Commonly found species include *Enterococcus faecalis* and *Enterococcus faecium* [102]. Notable infections caused by *Enterococci* include urinary tract infections, bacteremia, meningitis, endocarditis [103]. Antibiotics active against *Enterococci* include ampicillin, penicillin, nitrofurantoin and vancomycin [104]. *Enterococci* often possess intrinsic resistance towards β -lactam antibiotics and aminoglycosides. However, resistance of *Enterococci* to vancomycin has been reported in several studies [105–107].

A study in Czech Republic identified 228 enterococcal isolates from the intestinal tract of poultry. These isolates were found to be highly resistant to tetracycline (80%), erythromycin (59%) and ofloxacin (51%) but exhibited low resistance to ampicillin (3%) and ampicillin/sulbactam (3%) [105]. A similar trend of resistance was reported among 163 Enterococcal isolates from

poultry litter in the Abbotsford area of British Columbia, Canada. The identified enterococcal isolates were found to be highly resistant to lincomycin (80.3%), tetracycline (65.3%), penicillin (61.1%) but showed low resistance towards nitrofurantoin (3.8%), daptomycin (3.5%) and gentamycin (0.8%) [108]. There is a high possibility of multi-drug resistant enterococci in animal meat and fecal matter being transferred to humans [106].

4.13. *Proteus* species

Proteus is a genus of Gram-negative Proteobacteria which is widely distributed as saprophytes [109]. They are mainly found in decomposing animal matter, sewage, manure, mammalian intestine, human and animal fecal matter. They are mainly opportunistic pathogens responsible for nosocomial urinary and septic infections [110]. Three species, namely, *P. vulgaris*, *P. mirabilis* and *P. penneri* are the only opportunistic species responsible for human infections. Most strains of *P. mirabilis* are sensitive to ampicillin and cephalosporins whereas *P. vulgaris* strains are not sensitive to these antibiotics [109].

A study in Iran identified 54 *P. mirabilis* isolates from chicken intestines and 54 *P. mirabilis* isolates were screened for antimicrobial susceptibility to 13 antimicrobial agents. None of the *P. mirabilis* isolates in this study were found to be resistant to gentamycin. Over 90% of isolates were resistant to nalidixic acid, doxycycline and tetracycline. Less than a quarter of isolates were resistant to norfloxacin, ampicillin, amikacin and ceftriaxone. Nearly 96% of the isolates were resistant to at least two or more antibiotics. One isolate exhibited resistance to 10 antibiotics whereas three and five isolates were resistant to nine and seven antibiotics, respectively. The results showed that chicken could be a source of antibiotic resistant and multi-drug resistant *P. mirabilis* strains and these resistant strains can cause worldwide problem both for veterinary sector and public health [111].

A similar trend of antibiotic resistance was observed in 36 *P. mirabilis* isolates from chicken droppings from commercial poultry farms in Bangladesh. Nearly 95% of the isolates were resistant to tetracycline followed by nalidixic acid (89%) and almost 20% of the isolates were found to be resistant to ciprofloxacin and 84% of the isolates exhibited multidrug resistance [112].

5. Other species of importance

Infections from other bacterial species could also result in the use of antibiotics. These include Mycoplasmosis (caused by *Mycoplasma gallisepticum*, *Mycoplasma meleagridis* and *Mycoplasma synoviae*) [86], *Pasteurella multocida* and *Haemophilus gallinarum* infections [62, 113]. These infections usually require the use broad spectrum antibiotics including tylosin, aureomycin, terramycin, gallimycin, penicillin, erythromycin, sulfadimethoxine, sulfathiazole and other sulfa drugs administered either in the feed, drinking water or by injections [62].

6. Conclusion

Several bacterial species are the major causes of infections in poultry and other animal husbandry. Most of these infections are linked to foodborne outbreaks, live animal contact, poor

hygiene, and environmental exposure. With the emergence of antimicrobial resistance, the pathogenicity and virulence of these organisms have increased and treatment options are diminishing and also more expensive. Multidrug resistant bacteria have been found in poultry, poultry products, carcasses, litter and fecal matter of birds and these pose a risk to both handlers, consumers and a threat to global and public health. The above information also calls for increased surveillance measures and monitoring of antibiotic usage in both animal husbandry and humans throughout the world.

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