



The Alternatives of Antibiotics in Poultry Production for Reducing Antimicrobial Resistance

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ABSTRACT

Antibiotics are natural, semi-synthetic, or chemical compounds that have anti-microbial activity and are used in livestock and poultry production for a variety of reasons, including therapeutic and growth promotion. The use of antibiotics in poultry production has been associated with the development of resistant bacteria. The present study attempted to explain the role of antibiotics as poultry growth promoters, bacterial resistance, and risks for human health, with a special focus on some selected bacterial species isolated from poultry farms and products. Furthermore, the manuscript reviewed the literature on alternative feed additives to reduce the reliance on antibiotics. Microbial resistance is a significant global health concern that has been a top global threat in the 21st century. The use of antibiotics in poultry production as non-therapeutic or growth promoters is at low doses and continuously, associated with developing resistant bacteria. Meanwhile, antibiotic-resistant genes in humans may have their roots in the diets of animals treated with antibiotics. Developing bacterial resistance has encouraged researchers to reduce the reliance on antibiotics by identifying potential feed additives, such as essential oils, bacteriophages, antimicrobial peptides, probiotics, prebiotics, organic acid, and enzymes that improve the immune system functions, reduce morbidity and mortality, improve the growth performances of poultry, and preserve consumer health.

Keywords: Antibiotic, Antimicrobial resistance, Feed additive, Human, Poultry

INTRODUCTION

Poultry production is an important source of the human diet globally providing essential animal protein with a suitable nutritional composition for humans. However, it also poses potential health concerns in some cases. Antibiotics, which are created in laboratories or produced by a wide range of microorganisms, including fungi and bacteria (Sahu and Saxena, 2014; Abreu et al., 2023), vary in their antibacterial effects, mode of action, and physical, chemical, and pharmacological characteristics (Dutta et al., 2019). The bactericidal or bacteriostatic mechanisms of antibiotics are inhibition of protein synthesis, cell wall synthesis, cytoplasmic membrane synthesis, and DNA synthesis (Sahu and Saxena, 2014; Diaz-Sanchez et al., 2015; Abreu et al., 2023).

Antibiotics have been used for a wide range of purposes in livestock and poultry for the past few decades. As therapeutic agents, antibiotics treat infectious diseases with high doses applied for short periods against specific diseases. As prophylactic agents, antibiotics prevent certain infections at the subclinical stage, using low (sub-therapeutic) doses periodically for several days. In addition, antibiotics are used as growth promoters, administered at a very low dose regularly in livestock feed. According to the literature, global antibiotic use increased by 39% between 2000 and 2015 (Klein et al., 2018). This surge in antibiotic demand, especially in low- and middle-income countries, is driven by economic growth and increased animal consumption. In 2013, food animals consumed approximately 131,000 tons of antibiotics, a figure expected to rise to 200,000 tons by 2030 (Van Boeckel et al., 2017).

While utilizing antibiotics significantly improves poultry performance and farm economics, it also poses potential risks. The spread of antibiotic-resistant (ABR) strains into the environment and human transmission through the food chain, compounded by inadequate drug withdrawal protocols, can pose significant public health risks (Klein et al., 2018; Abreu et al., 2023). The current review aimed to provide an up-to-date overview of antibiotic use as a poultry growth promoter, as well as bacterial resistance, and human health risks. The present study also discussed alternatives to antibiotics in poultry production.

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ANTIBIOTICS AND POULTRY PRODUCTION

The antibiotic as a growth promoter was first discovered in 1940 when aureomycin-containing pharmaceutical wastes were fed to poultry (Castanon, 2007). Adding antibiotics to animal feed as growth promoters at a concentration of 200 gm per ton for more than 14 days is a common experiment in animal production (Diaz-Sanchez et al., 2015). Adding antibiotics to the poultry diet can positively affect poultry growth performance by preventing enteritis, reducing growth-depressing metabolites produced by gram-positive bacteria, improving intestinal microbiota balance, enhancing nutrient utilization efficiency, and increasing energy harvesting from the intestine (converting feed to products; Allen and Stanton, 2014; Agyare et al., 2019; Haque et al., 2023).

The antibiotics apply their effect on bacteria in a few well-defined ways called the mode of action (Table 1). DNA replication is the process used to generate two new daughter DNA molecules, which result in the division of a bacterial cell into two daughter cells (Nagaraja et al., 2017). Antibiotics, such as fluoroquinolones (Ciprofloxacin, Levofloxacin, and Moxifloxacin) inhibit the DNA gyrase and topoisomerase IV, preventing the synthesis of bacterial DNA (Shree et al., 2023). Protein biosynthesis inhibition includes essential bacteria protein synthesis which has DNA to encode mRNA, rRNA, and tRNA. The 50s and 30s ribosomal subunits make up the bacterial ribosome and play a role in bacterial protein synthesis. Antibiotics, such as aminoglycosides (Tetracycline) target the 30s ribosomal (Halawa et al., 2024), macrolides (Chloramphenicol and Oxazolidinone) target the 50s (Syroegin et al., 2022) and inhibit protein synthesis. Cell wall synthesis inhibition means the peptidoglycan is the most important part of the cell wall, and several steps are included to synthesize the same and form the bacterial cell wall. The distinctive structure of antibiotics, including beta-lactams (penicillins and cephalosporins) and glycopeptides allows them to bind to peptidoglycan cross-linking enzymes (transpeptidase and carboxypeptidase), inhibiting bacterial peptidoglycan synthesis and preventing cell wall formation. In folic acid metabolism inhibition some antibiotics, such as sulfonamide, inhibit the specific enzymes involved in folic acid metabolism (Capasso and Supuran, 2014).

Various health and food organizations developed guidelines for using antibiotics in livestock to address and prevent antibiotic resistance. The key guidelines for using veterinary antibiotics include the recommendation of antibiotics after diagnosis of diseases with bacterial etiology, administration of antibiotics under the supervision of a veterinarian, priority being given to the health status of an infected animal, improvement in the understanding and awareness of antibiotics resistance, implementation of effective sanitation, and infection prevention, and encouragement of sustainable investment to discover new effective medicines, diagnostic tools, and vaccines (Haag, 2015; Diaz-Sanchez et al., 2015; Salam et al., 2023).

ANTIMICROBIAL RESISTANCE

Antibiotic resistance (ABR), which is also known as antimicrobial resistance (AMR), and emerging infectious diseases are severe global health concerns. Antimicrobial agents used in livestock and poultry production and their AMR in contributing sources and are connected to serious illness and a heavy financial burden in individuals and different countries. Achieving sustainable development objectives, livelihood security, food safety, and nutrition security can all be impacted. Since humans, animals, and the environment are all interconnected as a cause and a cure, ABR is truly a one health issue (Wang et al., 2021a; Salam et al., 2023).

Both direct and indirect contact between the various actors and environments can spread drug resistance up the food chain, serving as pathways for the transmission of zoonotic diseases. Humans come into direct touch with resistant microorganisms found in animals or their products. Resistance strains are more likely to colonize or infect occupational workers, including farmers, veterinary professionals, abattoir workers, food handlers, and others with whom they come into contact (Salam et al., 2023). Antibiotic residues are the byproducts of antibiotic degradation or related metabolites that accumulate in manure, wastewater, and soils and have a significant negative impact. Therefore, the environment becomes a significant reservoir of antimicrobial drug resistance due to the spread of antibiotic-resistant bacteria and antibiotic residues via food and animal waste (Abreu et al., 2023).

Antimicrobial resistance arises when bacteria lose their susceptibility and acquire resistance to the medications employed for their treatment (Vikesland et al., 2019). Infections caused by these microbes are harder to treat due to the resistance they develop, leading to increased morbidity, mortality, and healthcare costs (Almansour et al., 2023). Bacteria utilize several approaches to resist the antibiotics, such as enzymatic degradation or modification of bacteria (e.g., chloramphenicol acetyltransferases), modification of the antibiotic target (e.g., vancomycin-resistant *enterococci*, which enzymatically modify peptidoglycan), and keeping the antibiotic out of the bacterial cell through either efflux pumps or alteration of the permeability of the cell membrane (Baker et al., 2023; Salam et al., 2023).

Table 1. Selected classes of commonly used antibiotics in poultry and humans, their action mechanisms, and activity spectrum

Antibiotic Class	Synthesis	Drug name	Action mechanism	Activity spectrum	Use in human and poultry	Reference
Tetracyclines	<i>Streptomyces</i> spp.	Oxytetracycline, Chlortetracycline, Doxycycline	Inhibition of protein synthesis	Gram-positive and gram-negative	In humans: Urinary tract, respiratory tract, and sexually transmitted infections In poultry: Respiratory infection and sinusitis, and growth promoter	(Chopra and Roberts, 2001)
Sulfonamides	Synthesized from non-natural compounds (Sulfanilamide) containing a sulfonamide group.	Sulfamethoxazole	Inhibiting folic acid-producing enzyme	Gram-positive and gram-negative	In humans: Urinary tract, respiratory tract, and skin infections In poultry: Restricted for infection treatment and banned as a growth promoter due to resistance concern	(Yoneyama and Katsumata, 2006)
Beta-lactams (Cephalosporins)	Synthesized from non-natural compounds (beta-lactam ring)	Amoxicillin, Efazolin, Meropenem	Inhibiting of penicillin-binding proteins	Gram-positive and gram-negative	In humans as well in poultry: For respiratory, urinary, sepsis, and sexually transmitted diseases, and as growth promoters in poultry	(Yoneyama and Katsumata, 2006)
Fluoroquinolones	Quinolone compounds	Ciprofloxacin, Levofloxacin, Moxifloxacin	Inhibiting bacterial DNA synthesis	Gram-positive and gram-negative	In humans: Respiratory, urinary tract, skin, and gastrointestinal infections In poultry: Colibacillosis, salmonellosis, respiratory infections, and as a growth promoter	(Gouvêa et al., 2015)
Macrolides	Derived from the macrolide ring	Azithromycin, Erythromycin	Inhibition of protein synthesis	Gram-positive and gram-negative	Use in humans: Pharyngitis, sinusitis, and bronchitis treatment In poultry: Respiratory infection, and as a growth promoter	(Yoneyama and Katsumata, 2006)
Aminoglycosides	<i>Streptomyces</i> spp.	Tobramycin, Gentamicin, Amikacin	Inhibition of protein synthesis	Gram-negative	In humans: Urinary, respiratory, and abdomen infections. In poultry: Has no use in poultry due to its potential residue, special care due to resistance and residue concern is required	(Tolmasky, 2000)
Monobactams	6-aminopenicillanic acid	Aztreonam	Inhibition of protein synthesis	Gram-negative	In humans: Urinary, respiratory, skin, and soft tissue infections. In poultry: Enteritis due to <i>Escherichia coli</i> (<i>E. coli</i>) and <i>Salmonella</i> , and has no use as a growth promoter	(Li et al., 2023)

ZOONOTIC MICROORGANISMS

Escherichia species

Escherichia coli (*E. coli*) is a pathogenic and commensal bacterium that causes infections, such as septicemia, cystitis, peritonitis, meningitis, and gastroenteritis in humans and animals (Zhang et al., 2020). The most imperative reservoirs for pathogenic *E. coli* are poultry and livestock (Yassin et al., 2017). Antimicrobials play a crucial role in animal farming by promoting the spread, emergence, and selection of AMR microbes (Abdalla et al., 2022). *E. coli* strains, which are part of human, animal, and environmental microbiotas, act as key indicators of AMR due to their resistance to antimicrobial agents and resistance gene accumulation (Poirel et al., 2018). Avian pathogenic *E. coli* is a major zoonotic disease that leads to significant financial losses for the poultry sector globally due to antibiotic resistance, primarily due to overuse and poor sanitation (Hamed et al., 2023). The world health organization (WHO) identifies *Salmonella* spp. and *E. coli* as the primary microorganisms to transmit AMR from poultry meats and products (Hamed et al., 2023).

E. coli isolates from poultry and animal farms showed resistance to at least three antimicrobial classes, while 94% showed resistance to at least one medication (Wang et al., 2021b). However, in a different investigation, the pathogenic *E. coli* which was isolated from chicken species showed a high level of resistance to widely used antimicrobials, such as colistin (82.88%), trimethoprim (89.04%), tetracycline (95.89%), and nalidixic acid (95.89%) (Bhave et al., 2019). The study revealed that 37% of turkey, 20% of chicken, 13% of duck, and 8% of game poultry *E. coli* isolates were multidrug-resistant fecal *E. coli* (Varga et al., 2019). A study by Ngai et al. (2021) revealed that 62% of *E. coli* isolates from chicken feed were resistant to ampicillin Benklaouz et al. (2020), looked at first-line antibiotics used on a chicken farm in Western Algeria to treat *E. coli*. The analysis indicated that of all the antibiotics employed in this study, nalidixic acid had the highest level of resistance (90.34%), followed by tetracycline (86.89%), ampicillin (82.75%), and other antibiotics. However, *E. Coli* isolates from the same investigation demonstrated ABR to colistin (84.64%), enrofloxacin (34.64%), neomycin (80.62%), norfloxacin, spectinomycin (0.89%), trimethoprim with sulfamethoxazole (53.47%), amoxicillin (24.38%), and amoxicillin with clavulanic acid (73.05%) (Benklaouz et al., 2020). Majewski et al. (2021) reported that the *E. coli* species frequently exhibit resistance to antimicrobials commonly employed for treating bacterial infections in poultry.

Salmonella species

Annually, 93.8 million cases of salmonellosis and 155,000 deaths are reported globally due to *Salmonella*, one of the most crucial zoonotic agents of *Salmonella* (Gong et al., 2023). The ABR bacteria list of the WHO now encompasses antimicrobial resistance against *Salmonella* as one of its top priorities (Tillotson, 2018). *Salmonella*, as a potential risk in poultry, is a common vector for the distribution of AMR to humans (Hoque et al., 2020). Food-borne zoonotic *enterobacterium* spp. can transmit ABR from animals' microbiomes to humans (Ali and Alsayeqh, 2022). However, *Salmonella* spp. infections are the most frequently reported bacterial diseases in poultry, which can potentially lead to human food-borne illnesses (El-Sharkawy et al., 2017). The development of multidrug resistance (MDR) in *Salmonella* strains may cause complications in treating humans and animals (Marin et al., 2022). Standard serological and microbiological techniques including polymerase chain reaction (PCR), conventional culture methods, immunology-based assays, miniaturized biochemical assays, and biosensors are usually used to isolate and identify *Salmonella* spp. (Kadry et al., 2019). The invasion gene (*invA*), often linked to bacterial virulence, is frequently used to accurately identify *Salmonella* spp. in clinical samples (Kadry et al., 2019).

Salmonella spp. is being considered as a potential AMR pathogen, originating from livestock, humans, and the environment (Pornsukarom et al., 2018). Non-typhoid *Salmonella* spp. is a major food-borne pathogen that globally infects humans and is linked to livestock and food (Mthembu et al., 2021). *Salmonella enterica*, comprising over 2600 serovars, is the most pathogenic species and is frequently linked to the contamination of poultry products (Jajere, 2019). Accordingly, inside the poultry production chain, the highest *Salmonella* isolates ABR levels were reported for nalidixic acid (80.3%) and ampicillin (64.8%, Castro-Vargas et al., 2020). The majority of the *Salmonella* isolates from chickens analyzed in another investigation were found to be resistant to trimethoprim/sulfamethoxazole, ciprofloxacin (73.17%), colistin (92.68%), and tigecycline (62.20%, Uddin et al., 2021). Poultry-related products, such as eggs can be exposed to pathogenic bacteria like *Salmonella*, either horizontally or vertically through transovarian transmission, which are crucial sources of pathogens (Borges et al., 2017). Adesiyun et al. (2020) revealed a 7.7% prevalence of resistant *Salmonella* spp. in eggs from layer farms in Gauteng Province, South Africa. *Salmonella* resistance in raw retail table eggs was found to be high, with 80% resistance against tetracycline and 60% resistance against ampicillin, indicating the presence of bacteria inside and outside the eggs (Kapena et al., 2020).

Staphylococcus species

Staphylococcus is a widely spread bacterium in the environments (air, dust, and household items), and are commensal colonizer of the mucous membranes and skin of humans and various animals including cats, cattle, and poultry (Lee et al., 2020). Ajoke et al. (2018) reported that 51 species and 27 subspecies of the genus *Staphylococcus*

have demonstrated resistance to all antibiotic classes utilized in their treatment through different mechanisms. *Staphylococci* are usually classified as either coagulase-negative (CoNS) or coagulase-positive (CoPS). The coagulase-positive *Staphylococcus aureus* (*S. aureus*) causes illnesses in animals and humans and is the most vital species in this genus which causes food intoxication (Lee et al., 2020). In addition, there are examples of resistant CoNS in poultry products, such as meat, eggs, and litter (Amoako et al., 2019). The major class of antibiotics used against *S. aureus* is beta-lactam, against which the *S. aureus* develops resistance often owing to a plasmid-encoded penicillinase/beta-lactamase (Pugazhendhi et al., 2020). However, methicillin-resistant *S. aureus* (MRSA) of livestock origin especially in poultry meat has been increasingly reported in recent years (Bortolaia et al., 2016). Another study by Ali et al. (2017) investigated the presence of MRSA in poultry samples and determined the highest resistance against penicillin-G (93.33%) and the lowest resistance was detected against neomycin (23.33%) against five antibiotics.

Non-*aureus* *Staphylococci* (NAS), which includes CoNS, have been identified as potential sources of food poisoning and significant contributors to opportunistic infections in humans and animals in recent times (Lee et al., 2020). Multidrug resistance in NAS, particularly *S. agnetis* (19.4%) and *S. chromogenes* (14.5%) with high rates against tetracycline and fluoroquinolones, was confirmed. Tetracycline resistance was linked to mutations in *gyrA* and *parC*, while fluoroquinolone resistance was linked to *QRDR* mutations (Lee et al., 2020). Ogundipe et al. (2020) explored the AMR against MRSA in chicken meat, chickens, live poultry markets, and environmental samples within poultry farms in southwestern Nigeria. The study found that 56 MRSA isolates were detected in tested samples which demonstrated 100%, 60.7%, 33.9%, 28.6%, 32.1%, and 10.7% resistance to beta-lactams, tetracycline, ciprofloxacin, erythromycin, gentamicin, and trimethoprim/sulfamethoxazole, respectively. Accordingly, live poultry markets may be a major source of MRSA infections among the general public and that chicken meat is tainted with the disease. Moreover, every isolate of *S. aureus* and *Streptococcus* spp. tested was 100% resistant to the majority of the antibiotics that were evaluated for poultry (Sharma et al., 2017). According to Rao et al. (2022), the highest AMR of *Streptococcus* spp. against clindamycin was found, followed by erythromycin and penicillin. Furthermore, a study on CNS isolated from Polish poultry revealed that fewer CNS strains exhibited genes resistant to macrolides, chloramphenicol/florfenicol, and lincosamides (Pyzik et al., 2019).

***Campylobacter* species**

Campylobacter spp. are emerging infections responsible for 95% of diarrhea cases in humans (Kirk et al., 2015). *Campylobacteriosis* is a human disease caused by contaminated foods and drinks, with broilers being the primary source of *Campylobacter* and meat in many countries (Tang et al., 2020; Gao et al., 2023). The use of antibacterial drugs like macrolides, fluoroquinolones, and tetracyclines to treat *Campylobacter* infections has been criticized for causing global fluoroquinolone resistance and macrolide-resistant strains (Gahamanyi et al., 2021). *Campylobacter* from food-producing animals shows high tetracycline resistance, with strains resistant to erythromycin, tetracycline, and ciprofloxacin becoming more prevalent (Gao et al., 2023). Viswanathan et al. (2017) found that cattle *Campylobacter* isolates showed higher ABR compared to wildlife isolates, with *Campylobacter jejuni* being more common but showing multidrug resistance. A study in Casablanca, Morocco, found that tetracycline (100% resistance against *Campylobacter jejuni* isolates) and gentamicin (12.0% resistance) were the most effective antibiotics (Es-Soucratti et al., 2020). *Campylobacter jejuni* AMR profiles from a Moroccan poultry farm revealed the highest resistance to co-trimoxazole (84.1%), cephalothin (81.1%), and tetracycline (59.4%) in poultry meat and associated samples (Khan et al., 2018). *Campylobacter jejuni* indicated no resistance to gentamicin, erythromycin, or kanamycin, but resistance was observed to tetracycline (78.6%), ciprofloxacin (87.8%), and nalidixic acid (81.6%, Adiguzel et al., 2018). Using the microdilution method, 93 *Campylobacter* spp. (45 *Campylobacter jejuni* and 25 *Campylobacter coli* from chickens; 23 *Campylobacter coli* from pigs) were examined for resistance to antibiotics to nine antimicrobial agents. There were lower resistance rates to florfenicol (8.6%), but higher resistance rates to nalidixic acid (79.6%), erythromycin (75.3%), tetracycline (68.8%), azithromycin (66.7%), ciprofloxacin (64.5%), and gentamicin (35.5%, Tang et al., 2020). Excessive antibiotic use in humans and animals has increased ABR infections, particularly resistant to fluoroquinolones. Understanding AMR mechanisms in *Campylobacter* spp. is crucial for improved ABR programs.

PUBLIC HEALTH

It is well known that ABR bacteria develop and propagate in animals, humans, and the environment, posing a cross-boundary concern that impacts ecosystems and public health. Poultry, their products, carcasses, litter, and bird feces have been reported to have MDR bacteria, which can be a threat to handlers, consumers, and in general to public health (Agyare et al., 2019). The ABR bacteria and resistance genes developed in livestock transfer to humans through various channels, particularly through the food chain (Figure 1). Many of these bacteria are serious human pathogens. *Campylobacter* spp. is the primary culprit behind cases of food-borne diarrhea in humans. For instance, *Campylobacter*

spp. is a leading cause of food-borne diarrhea worldwide, responsible for 4-5 hundred million cases annually (Chibwe et al., 2023). In immunocompromised or elderly persons, as well as in extremely young children, infections caused by *Campylobacter* can be severe or even fatal. *E. coli* bacteria are another widespread cause of sickness. Furthermore, Salmonellosis is one of the world's most widespread and common food-borne infections that result in mild gastroenteritis (Mehdi et al., 2018).

Based on the literature, people from impoverished and developing countries are the most vulnerable to ABR bacteria threats. It is estimated that at least 700,000 people die each year as a result of resistant bacterial infections, a figure that is expected to rise to 10 million globally by 2050, in case the current trends continue. Furthermore, the worldwide cost of ABR is predicted to increase to \$100 trillion in the coming decades (Crofts et al., 2017).

The risk of ABR bacteria in poultry production can be reduced through several approaches, including the utilization of antibiotics alternatives, prevention of environmental contaminations, and improvements in all stages of the poultry production system, such as poultry health, biosecurity, cleaning procedures, and implementing hazard analysis (Abreu et al., 2023; Salam et al., 2023).

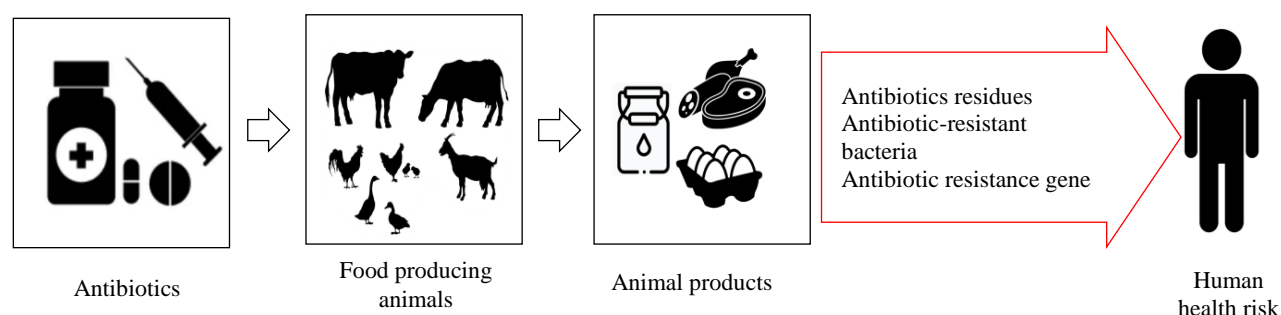


Figure 1. Human health concerns about antibiotic resistance bacteria in animal sources

ALTERNATIVES OF ANTIBIOTICS IN POULTRY PRODUCTION

Feed additives aim to reduce the reliance on antibiotics by identifying feed additives that stimulate the immune system, decrease morbidity and mortality, improve the growth performances of poultry, and preserve consumer health (Rahman et al., 2022). The modern chicken industry needs high levels of output and effective feed conversion, which can be partially attained by articular feed additives (Alagawany et al., 2016; Khan and Iqbal, 2016; Azizi et al., 2021a; 2021b, Danladi et al., 2022). Researchers have investigated several groups of feed additives and their prospective application as alternatives to antibiotics in poultry production (Rahman et al., 2022). Studying the overall alternatives for antibiotics used in poultry feeding as growth promoters is a controversial topic. Therefore, in the present review, the most frequently used feed additives, such as essential oils, phytochemicals, bacteriophages, antimicrobial peptides, probiotics, prebiotics, organic acids, and enzymes are discussed briefly.

Essential oils

Essential oils and nano-emulsions can be cutting-edge alternatives for antibiotics that reduce bacterial infections, and improve gut health intestinal environment, and gastrointestinal tract enzyme activities in chickens (Abd El-Hack et al., 2022). Nanoencapsulation herbal essential oils increase the growth performance of broiler chickens and efficiently work against antibiotic-resistant pathogens (Meimandipour et al., 2017). Similarly, ginger, garlic, limes, and lemongrass as sources of essential oil used in poultry nutrition increase the health performance of broiler chickens (Amiri et al., 2021). In addition, the application of herbal essential oils in poultry nutrition has positive effects on the antioxidant capacity, immunity, and growth performance of chickens (Linh et al., 2022). In another study, essential oils from garlic and cumin in nano-encapsulated form improved some structural features of the digestive tract including villi width and length (Amiri et al., 2021). Additionally, it has been identified that herb extracts, such as oregano, effectively inhibit the proliferation of pathogenic coliform bacteria in broiler chickens without affecting the proliferation of beneficial microbes (Mohebodini et al., 2019). The mechanism underlying the effectiveness of essential oils in poultry nutrition may involve bioactive components that enhance the production of the mucin-2 gene in the digestive tract. Mucin-2 plays a crucial role in protecting the gastrointestinal tract from infections, aiding in the secretion of digestive enzymes, and maintaining acidic conditions (Amiri et al., 2020). Furthermore, the chemical components present in the essential oils stimulate the secretion of digestive enzymes from the mucosal layer of the intestine (Jemaa et al., 2018). Thus, essential oil could be a

potential alternative to antibiotics in poultry nutrition for increasing growth performance, as well as producing low-cholesterol meat with high quality and durability (Namdeo et al., 2022).

Phytochemicals

Phytochemicals, which are secondary metabolites derived from natural plant sources, are utilized in poultry nutrition as feed additives due to their potential antimicrobial properties and ability to enhance chicken growth performance (Hashemi et al., 2008). The inclusion of phytochemicals in poultry diets has been shown to effectively replace antibiotics, improving growth performance and overall poultry production (Valenzuela-Grijalva et al., 2017; Azizi et al., 2023). These compounds possess antimicrobial, antioxidant, and anti-stress properties, contributing to enhanced immune responses, growth performance, and modulation of gut microbiota in broiler chickens (Chowdhury et al., 2018; Al-Mnaser et al., 2022; Azizi et al., 2023). Moreover, phytochemicals promote the growth of beneficial bacteria while reducing the population of pathogenic bacteria (Cencic and Chingwaru, 2010). This reshaping of the gut microbial community, alongside increased activity of digestive enzymes like amylase and maltase, likely underlies their mechanism of action (Jang et al., 2007; Al-Mnaser et al., 2022). Overall, incorporating phytochemicals as feed additives represents a promising alternative to antibiotics in poultry nutrition, enhancing metabolism, growth, antioxidant capacity, and immune function in chickens (Hassan et al., 2022).

Bacteriophages

According to Żbikowska et al. (2020), bacteriophages are a unique type of viruses that exclusively infect bacteria and are considered non-pathogenic to humans. In the poultry industry, bacteriophages are gaining attention as a promising alternative to antibiotics due to their high specificity (Lin et al., 2017). Research has demonstrated that bacteriophages can effectively control various pathogenic bacteria in chickens (Hong et al., 2013; Lee et al., 2016). Studies have shown that adding a 0.05% bacteriophage cocktail can enhance the immune system and promote the growth of beneficial gut microorganisms (Upadhaya et al., 2021). Dietary supplementation with bacteriophages has also been found to improve growth performance in broiler chickens and reduce the populations of specific pathogenic bacteria in their gastrointestinal tract (Kim et al., 2014). Similarly, feeding bacteriophages has been shown to enhance production efficiency in both broilers and layers and reduce overall excreta microflora levels (Noor et al., 2020). The improved microbiological environment in the gastrointestinal tract of broilers and layers appears to be the underlying mechanism (Lee et al., 2016). Thus, the findings from several studies suggest that bacteriophage dietary supplementation would be a safe alternative to antibiotics for raising broiler chickens.

Antimicrobial peptides

Antimicrobial peptides (AMPs), also known as host defence peptides, offer a promising alternative to antibiotics when used as feed additives in poultry nutrition (Kurt et al., 2019). The AMPs have been shown to positively impact gut microbiota and enhance overall health and performance in chickens. Research indicates that incorporating AMPs into poultry diets improves intestinal microbiota balance, intestinal morphology, nutritional digestibility, and growth rates (Wang et al., 2016). By promoting a healthy and immune-competent gut microbiota, AMPs contribute to enhanced growth performance metrics such as feed conversion efficiency, daily weight gain, feed intake, and reduced mortality (Nazeer et al., 2021). Bacteriocins, which are ribosomally synthesized antibacterial peptides, are another form of AMPs that show potential for controlling bacterial diseases and serving as alternatives to antibiotics (Ben Lagha et al., 2017). Studies have demonstrated that synthetic AMPs can increase feed intake and growth performance while protecting against intestinal damage in broiler chickens (Choi et al., 2013). Additionally, AMPs from various sources have been found to modulate the expression of pro-inflammatory and anti-inflammatory molecules in the intestine, improve intestinal morphology, enhance digestion processes, and regulate the immune system in broilers (Abreu et al., 2023). As immune modulators, AMPs also help reduce bacterial infection rates in broilers (Choi et al., 2013). The AMPs perform several antibacterial activities through several mechanisms that have been previously reviewed (Wang et al., 2016). These mechanisms include the suppression of nucleic acid and protein synthesis, the inhibition of enzymatic activities, and cell membrane synthesis (Brogden, 2005).

Probiotic

Due to the detrimental effects associated with antibiotics used in poultry nutrition, including dysbiosis, ABR, and elimination of beneficial microbial communities in the intestine (Yang et al., 2021), alternative approaches like probiotics are increasingly considered (Alagawany et al., 2016). Probiotics consist of living microorganisms that confer health benefits to the host when administered in adequate amounts (Rahman et al., 2022). Various probiotic microbe families are utilized as feed additives in the nutrition of poultry (Floch, 2014). Probiotics have been shown to have

beneficial and protective effects in several areas, such as improving growth and productive performances as well as egg quality. They also have applications as beneficial bacteria to reduce harmful bacteria, improve nutrient absorption and digestion, increase production, and protect the health of chickens (Ritzi et al., 2014; Alagawany et al., 2016; Popova, 2017). In Japanese quails, the lower dose of kefir administered as a probiotic reduced stress effect, liver weight, and alkaline phosphatase activity (Vahdatpour and Babazadeh, 2016). The use of synbiotics combined with the vaccine for infectious bursal disease promoted both the growth performance and related antibody titers (Babazadeh and Asasi, 2021).

Due to their negative proportional relationship, recent research showed that probiotics affect antimicrobial peptide modulation in chickens (Ma et al., 2020; Rahman et al., 2022). The antimicrobial peptide gene expression was reduced as probiotic concentration increased, suggesting that antimicrobial peptides might not always be required when probiotics are present (Akbari et al., 2008; Schlee et al., 2008). Furthermore, research indicates that adding probiotics to the diet during the later stages of reproduction can enhance the laying ducks' productivity and egg quality (Cao et al., 2022).

Prebiotic

The term prebiotics was first coined to describe non-digestible food components that provide benefits to the host by selectively promoting the growth or activity of specific bacteria in the colon (Floch, 2014). Chemically, prebiotics are carbohydrates with a short carbon chain that selectively increase the activity of certain types of beneficial bacteria in the gut (Kolida and Gibson, 2011; Al-Sheraji et al., 2013). Prebiotics are broken down by beneficial bacteria in the gut to produce short-chain fatty acids (Mountzouris and Tsirtsikos, 2009). Other health benefits of prebiotics in the large intestine include reduced cancer risk and enhanced gastrointestinal absorption of calcium and magnesium (Karakan et al., 2021). Different oligosaccharides have been evaluated in poultry feed as prebiotics, and their effects on the gastrointestinal microbiome of the chickens and the inhibition of pathogenic bacteria have been described by Clavijo and Flórez (2018).

Prebiotics have been associated with multiple mechanisms and roles that affect the avian gastrointestinal microbiota, including immune system interaction, alterations in intestinal morphology, and competitive elimination of pathogenic microorganisms (Pourabedin and Zhao, 2015). Prebiotics may be metabolized by a wide variety of gastrointestinal bacteria, which makes it more difficult to comprehend how they benefit the host and/or prevent the growth of pathogens (Alloui et al., 2013). However, further research is required to explore the exact mechanism behind the health and growth-promoting effects of prebiotics on livestock.

Organic acid

It has been established that short-chain organic acids (C1-C7) have antibacterial effects. Based on chemical structure, organic acids are divided into two groups, namely simple mono-carboxylic acids like butyric, propionic, fumaric, and sorbic acids, and short-chain carboxylic acids with double bonds like fumaric and sorbic acids (Wang et al., 2009; Scicutella et al., 2021). Another category of organic acids is carboxylic acids with an extra hydroxyl group including lactic, malic, tartaric, and citric acids (Shahidi et al., 2014). Due to their widespread safety, the European Union approved the use of organic acids and their salts in poultry production (Adil et al., 2010). The majority of organic acids with antimicrobial action have a pH of 3 to 5, and variable chemical and physical characteristics (Scicutella et al., 2021). Many of these acids are utilized in poultry nutrition as feed additives or as supplements to drinking water (acidifiers; Khan and Iqbal, 2016). It was found that organic acid mixtures (calcium format, calcium propionate, potassium sorbate, calcium butyrate, calcium lactate, and hydrogenated oil of vegetable) used in poultry nutrition were more effective at reducing intestinal *Salmonella* spp. and *E. coli* than the antibiotic growth promoter such as Enramycin (Hassan et al., 2010). The total bacterial count in ceca was significantly lower in the groups that received drinking water treatments with acetic acid (3 mL/L) and an organic acid mixture (3 mL/L; acetic acid, phosphoric acid, lactic acid, fumaric acid, and tartaric acid) 7 days after infection than in the non-treated group (Hamed and Hassan, 2013). Some types of organic acids perform effectively against organisms that cannot tolerate acidity (Cao et al., 2022). Organic acids improve nutrient digestibility by reducing endogenous nitrogen losses and microbial competition with the host for nutrients, as well as by lowering the incidence of subclinical infections and the secretion of immune mediators and by reducing the production of ammonia and other growth-depressing microbial metabolites (Khan and Iqbal, 2016).

Enzymes

Enzymes have gained prominence in poultry nutrition as effective feed additives, addressing challenges posed by anti-nutritional factors and optimizing nutrient digestion and utilization (Son and Ravindran, 2012; Pirgozliev et al., 2019). Enzymes that are commonly utilized in poultry nutrition include non-starch polysaccharides, which break down

the non-starch polysaccharides in viscous cereals, and microbial phytases, which target phytate-complexes in plant components (Amerah et al., 2011; Cross et al., 2011).

Particularly in young chickens, proteases play a significant role in the digestion of protein and amino acids (Pirgozliev et al., 2015). In addition to acting as antioxidants, dietary phytogenic may impact immunological function, nutritional availability, endogenous secretions, and daily feed consumption (Amerah et al., 2011; Cross et al., 2011). Enhancing animal performance through increased feed intake, weight gain, and feed efficiency is the ultimate goal of applying feed enzymes (Rahman et al., 2022). The underlying mechanism may be the breakdown of certain bonds in feed components that are not usually digested by endogenous digestive enzymes (Selle and Ravindran, 2007; Son and Ravindran, 2012), degradation of ant-nutritional elements that limit the digestion of nutrients and cause modifications to the intestinal tract's morphology (Bedford, 2000; Wu et al., 2004). Moreover, the positive effects of the enzyme may be due to the decreases in intestinal protein wastes and endogenous secretions, which reduces the amount of protein required for maintenance, and alterations to the small and large intestine's microbiota profile (Apajalathi et al., 2004; Cowieson and Ravindran, 2007).

CONCLUSION

The use of antibiotics in poultry production has been associated with the development of resistant bacteria. The spread of ABR bacteria in the environment and their transmission to humans could have serious consequences for public health. *Salmonella* spp., *E. coli*, *Campylobacter* spp., and *Staphylococcus* spp. are considered very common ABR bacteria isolated from poultry products. A ban on the use of non-therapeutic antibiotics would help to minimize additional harm to food safety, contamination of the environment, and overall health risks. Further studies are required to create substitute approaches, such as the utilization of alternative bioactive compounds as feed additives for instance essential oils, bacteriophages, antimicrobial peptides, probiotics, prebiotics, organic acid, and enzymes, and discovering their exact action mechanisms to maintain poultry health and productivity, environmental contaminations as well as preserve consumer health.

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Authors' contribution

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Competing interests

The authors disclose no conflict of interest.

Ethical consideration

Ethical issues (including plagiarism, consent to publish, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy) have been checked by all the authors.

Availability of data and materials

All data related to the present review are presented in this article.

REFERENCES

Abd El-Hack ME, El-Saadony MT, Saad AM, Salem HM, Ashry NM, Abo Ghanima MM, Shukury M, Swelum AA, Taha AE, El-Tahan AM et al. (2022). Essential oils and their nanoemulsions as green alternatives to antibiotics in poultry nutrition: A comprehensive review. *Poultry Science*, 101(2): 101584. DOI: <https://www.doi.org/10.1016/j.psj.2021.101584>

- Abdalla SE, Abia ALK, Amoako DG, Perrett K, Bester LA, and Essack SY (2022). Food animals as reservoirs and potential sources of multidrug-resistant diarrheagenic *E. coli* pathotypes: Focus on intensive pig farming in South Africa. *Onderstepoort Journal of Veterinary Research*, 89(1): a1963. DOI: <https://www.doi.org/10.4102/ojvr.v89i1.1963>
- Abreu R, Semedo-Lemsaddek T, Cunha E, Tavares L, and Oliveira M (2023). Antimicrobial drug resistance in poultry production: Current status and innovative strategies for bacterial control. *Microorganisms*, 11(4): 953. DOI: <https://www.doi.org/10.3390/microorganisms11040953>
- Adesiyun AA, Nkuna C, Mokgoathheng-Mamogobo M, Malepe K, and Simanda L (2020). Food safety risk posed to consumers of table eggs from layer farms in Gauteng Province, South Africa: Prevalence of *Salmonella* species and *Escherichia coli*, antimicrobial residues, and antimicrobial resistant bacteria. *Journal of Food Safety*, 40(3): e12783. DOI: <https://www.doi.org/10.1111/jfs.12783>
- Adiguzel MC, Sigirci BD, Celik B, Kahraman BB, Metiner K, Ikiz S, Bagcigil AF, Ak S, and Ozgur NY (2018). Phenotypic and genotypic examination of antimicrobial resistance in thermophilic *Campylobacter* species isolated from poultry in Turkey. *Journal of Veterinary Research*, 62(4): 463-468. DOI: <https://www.doi.org/10.2478/jvetres-2018-0071>
- Adil S, Banday T, Bhat GA, Mir MS, and Rehman M (2010). Effect of dietary supplementation of organic acids on performance, intestinal histomorphology, and serum biochemistry of broiler chicken. *Veterinary Medicine International*, 2010: 479485. DOI: <https://www.doi.org/10.4061/2010/479485>
- Agyare C, Etsiapa Boamah V, Ngofi Zumbi C, and Boateng Osei F (2019). Antibiotic Use in poultry production and its effects on bacterial resistance. In: Y. Kumar (Editor), *Antimicrobial resistance- A global threat*. IntechOpen, pp. 1-13. DOI: <https://www.doi.org/10.5772/intechopen.79371>
- Ajoke M, Kumar A, and Njie C (2018). Genetic characterization of antibiotic-resistant *Staphylococcus aureus* from milk in the North-West Province, South Africa. *Saudi Journal of Biological Sciences*, 25(7): 1348-1355. DOI: <https://www.doi.org/10.1016/j.sjbs.2015.10.011>
- Akbari MR, Haghighi HR, Chambers JR, Brisbin J, Read LR, and Sharif S (2008). Expression of antimicrobial peptides in cecal tonsils of chickens treated with probiotics and infected with *Salmonella enterica* serovar typhimurium. *Clinical and Vaccine Immunology*, 15(11): 1689-1693. DOI: <https://www.doi.org/10.1128/CVI.00242-08>
- Al-Sheraji SH, Ismail A, Manap MY, Mustafa S, Yusof RM, and Hassan FA (2013). Prebiotics as functional foods: A review. *Journal of Functional Foods*, 5(4): 1542-1553. DOI: <https://www.doi.org/10.1016/j.jff.2013.08.009>
- Al-Mnaser A, Dakheel M, Alkandari F, and Woodward M (2022). Polyphenolic phytochemicals as natural feed additives to control bacterial pathogens in the chicken gut. *Archives of Microbiology*, 204(5): 253. DOI: <https://www.doi.org/10.1007/s00203-022-02862-5>
- Alagawany M, Abd El-Hack ME, Arif M, and Ashour EA (2016). Individual and combined effects of crude protein, methionine, and probiotic levels on laying hen productive performance and nitrogen pollution in the manure. *Environmental Science and Pollution Research*, 23(22): 22906-22913. DOI: <https://www.doi.org/10.1007/s11356-016-7511-6>
- Ali S and Alsayeqh AF (2022). Review of major meat-borne zoonotic bacterial pathogens. *Frontiers in Public Health*, 10: 1045599. DOI: <https://www.doi.org/10.3389/fpubh.2022.1045599>
- Ali Y, Islam MA, Muzahid NH, Sikder MOF, Hossain MA, and Marzan LW (2017). Characterization, prevalence and antibiogram study of *Staphylococcus aureus* in poultry. *Asian Pacific Journal of Tropical Biomedicine*, 7(3): 253-256. DOI: <https://www.doi.org/10.1016/j.apjtb.2016.12.001>
- Allen HK and Stanton TB (2014). Altered egos: Antibiotic effects on food animal microbiomes. *Annual Review of Microbiology*, 68(1): 297-315. DOI: <https://www.doi.org/10.1146/annurev-micro-091213-113052>
- Alloui MN, Szczurek W, and Świątkiewicz S (2013). The usefulness of prebiotics and probiotics in modern poultry nutrition: A review. *Annals of Animal Science*, 13(1): 17-32. DOI: <https://www.doi.org/10.2478/v10220-012-0055-x>
- Almansour AM, Alhadlaq MA, Alzahrani KO, Mukhtar LE, Alharbi AL, and Alajel SM (2023). The silent threat: Antimicrobial-resistant pathogens in food-producing animals and their impact on public health. *Microorganisms*, 11(9): 1-25. DOI: <https://www.doi.org/10.3390/microorganisms11092127>
- Amerah AM, Péron A, Zaeferian F, and Ravindran V (2011). Influence of whole wheat inclusion and a blend of essential oils on the performance, nutrient utilisation, digestive tract development and ileal microbiota profile of broiler chickens. *British Poultry Science*, 52(1): 124-132. DOI: <https://www.doi.org/10.1080/00071668.2010.548791>
- Amiri N, Afsharmanesh M, Salarmoini M, Meimandipour A, Hosseini SA, and Ebrahimnejad H (2021). Nanoencapsulation (*in vitro* and *in vivo*) as an efficient technology to boost the potential of garlic essential oil as alternatives for antibiotics in broiler nutrition. *Animal*, 15(1): 100022. DOI: <https://www.doi.org/10.1016/j.animal.2020.100022>
- Amiri N, Afsharmanesh M, Salarmoini M, Meimandipour A, Hosseini SA, and Ebrahimnejad H (2020). Effects of nanoencapsulated cumin essential oil as an alternative to the antibiotic growth promoter in broiler diets. *Journal of Applied Poultry Research*, 29(4): 875-885. DOI: <https://www.doi.org/10.1016/j.japr.2020.08.004>
- Amoako DG, Somboro AM, Abia ALK, Allam M, Ismail A, Bester L, and Essack Sy (2019). Genomic analysis of methicillin-resistant *Staphylococcus aureus* isolated from poultry and occupational farm workers in Umgungundlovu District, South Africa. *Science of the Total Environment*, 670: 704-716. DOI: <https://www.doi.org/10.1016/j.scitotenv.2019.03.110>
- Apajalathi J, Kettunen A, and Graham H (2004). Characteristics of the gastrointestinal microbial communities, with special reference to the chicken. *World's Poultry Science Journal*, 60(2): 223-232. DOI: <https://www.doi.org/10.1079/wps200415>
- Azizi MN, Loh TC, Foo HL, Akit H, Izuddin WI, Shazali N, Chung ELT, and Samsudin AA (2021a). Chemical compositions of brown and green seaweed, and effects on nutrient digestibility in broiler chickens. *Animals*, 11(7): 2147. DOI: <https://www.doi.org/10.3390/ani11072147>
- Azizi MN, Loh TC, Foo HL, and Chung ELT (2021b). Is palm kernel cake a suitable alternative feed ingredient for poultry?. *Animals*, 11(2): 338. DOI: <https://www.doi.org/10.3390/ani11020338>
- Azizi MN, Loh TC, Foo HL, Akit H, Izuddin WI, and Yohanna D (2023). Brown and green seaweed antioxidant properties and effects on blood plasma antioxidant enzyme activities, hepatic antioxidant genes expression, blood plasma lipid profile, and meat quality in broiler chickens. *Animals*, 13(10): 1582. DOI: <https://www.doi.org/10.3390/ani13101582>
- Baker KS, Jauneikaite E, Hopkins KL, Lo SW, Sánchez-Busó L, Getino M, Howden BP, Holt KE, Musila LA, Hendriksen RS et al. (2023). Genomics for public health and international surveillance of antimicrobial resistance. *The Lancet Microbe*, 5247(23): E1047-E1055. DOI: [https://www.doi.org/10.1016/s2666-5247\(23\)00283-5](https://www.doi.org/10.1016/s2666-5247(23)00283-5)
- Babazadeh D and Asasi K (2021). Effects of *in ovo* synbiotic injection on growth performance, intestinal bacterial load and antibody titres in broiler chickens vaccinated against infectious bursal disease. *Bulgarian Journal of Veterinary Medicine*, 24(4): 520-532. DOI: <https://www.doi.org/10.15547/bjvm.2298>
- Bedford M (2000). Removal of antibiotic growth promoters from poultry diets: Implications and strategies to minimise subsequent problems. *World's Poultry Science Journal*, 56(4): 362-365. DOI: <https://www.doi.org/10.1079/wps20000024>
- Ben Lagha A, Haas B, Gottschalk M, and Grenier D (2017). Antimicrobial potential of bacteriocins in poultry and swine production. *Veterinary Research*, 48(1): 22. DOI: <https://www.doi.org/10.1186/s13567-017-0425-6>
- Benklaouz MB, Aggad H, and Benameur Q (2020). Resistance to multiple first-line antibiotics among *Escherichia coli* from poultry in Western Algeria. *Veterinary World*, 13(2): 290-295. DOI: <https://www.doi.org/10.14202/vetworld.2020.290-295>

- Bhave S, Kolhe R, Mahadevaswamy R, Bhong C, Jadhav S, Nalband S, Gandhale D, and Muglikar D (2019). Phylogrouping and antimicrobial resistance analysis of extraintestinal pathogenic *Escherichia coli* isolated from poultry species. *Turkish Journal of Veterinary and Animal Sciences*, 43(1): 117-126. DOI: <https://www.doi.org/10.3906/vet-1808-47>
- Borges KA, Furian TQ, De Souza SN, Tondo EC, Streck AF, Salle CTP, de Souza Moraes HL, and do Nascimento VP (2017). Spread of a major clone of *Salmonella enterica* serotype enteritidis in poultry and in salmonellosis outbreaks in Southern Brazil. *Journal of Food Protection*, 80(1): 158-163. DOI: <https://www.doi.org/10.4315/0362-028X.JFP-16-299>
- Brogden KA (2005). Antimicrobial peptides: Pore formers or metabolic inhibitors in bacteria?. *Nature Reviews Microbiology*, 3(3): 238-250. DOI: <https://www.doi.org/10.1038/nrmicro1098>
- Bortolaia V, Espinosa-Gongora C, and Guardabassi L (2016). Human health risks associated with antimicrobial-resistant enterococci and *Staphylococcus aureus* on poultry meat. *Clinical Microbiology and Infection*, 22(2): 130-140. DOI: <https://www.doi.org/10.1016/j.cmi.2015.12.003>
- Cao Y, Xun M, Ren S, and Wang J (2022). Effects of dietary organic acids and probiotics on laying performance, egg quality, serum antioxidants and expressions of reproductive genes of laying ducks in the late phase of production. *Poultry Science*, 101(12): 102189. DOI: <https://www.doi.org/10.1016/j.psj.2022.102189>
- Capasso C and Supuran CT (2014). Sulfa and trimethoprim-like drugs-antimetabolites acting as carbonic anhydrase, dihydropteroate synthase and dihydrofolate reductase inhibitors. *Journal of Enzyme Inhibition and Medicinal Chemistry*, 29(3): 379-387. DOI: <https://www.doi.org/10.3109/14756366.2013.787422>
- Castanon JIR (2007). History of the use of antibiotic as growth promoters in European poultry feeds. *Poultry Science*, 86(11): 2466-2471. DOI: <https://www.doi.org/10.3382/ps.2007-00249>
- Castro-Vargas RE, Herrera-Sánchez MP, Rodríguez-Hernández R, and Rondón-Barragán IS (2020). Antibiotic resistance in *Salmonella* spp. isolated from poultry: A global overview. *Veterinary World*, 13(10): 2070-2084. DOI: <https://www.doi.org/10.14202/vetworld.2020.2070-2084>
- Cencic A and Chingwaru W (2010). The role of functional foods, nutraceuticals, and food supplements in intestinal health. *Nutrients*, 2(6): 611-625. DOI: <https://www.doi.org/10.3390/nu2060611>
- Chibwe M, Odume ON, and Nnadozie CF (2023). A review of antibiotic resistance among *Campylobacter* species in human, animal, and water sources in South Africa: A One Health Approach. *Journal of Water and Health*, 21(1): 9-26. DOI: <https://www.doi.org/10.2166/wh.2022.146>
- Choi SC, Ingale SL, Kim JS, Park YK, Kwon IK, and Chae BJ (2013). An antimicrobial peptide-A3: Effects on growth performance, nutrient retention, intestinal and faecal microflora and intestinal morphology of broilers. *British Poultry Science*, 54(6): 738-746. DOI: <https://www.doi.org/10.1080/00071668.2013.838746>
- Chopra I and Roberts M (2001). Tetracycline antibiotics: Mode of action, applications, molecular biology, and epidemiology of bacterial resistance. *Microbiology and Molecular Biology Reviews*, 65(2): 232-260. DOI: <https://www.doi.org/10.1128/mmb.65.2.232-260.2001>
- Chowdhury S, Mandal GP, Patra AK, Kumar P, Samanta I, Pradhan S, and Samanta AK (2018). Different essential oils in diets of broiler chickens: 2. Gut microbes and morphology, immune response, and some blood profile and antioxidant enzymes. *Animal Feed Science and Technology*, 236: 39-47. DOI: <https://www.doi.org/10.1016/j.anifeeds.2017.12.003>
- Clavijo V and Flórez MJV (2018). The gastrointestinal microbiome and its association with the control of pathogens in broiler chicken production: A review. *Poultry Science*, 97(3): 1006-1021. DOI: <https://www.doi.org/10.3382/ps/pex359>
- Cowieson AJ and Ravindran V (2007). Effect of phytic acid and microbial phytase on the flow and amino acid composition of endogenous protein at the terminal ileum of growing broiler chickens. *British Journal of Nutrition*, 98(4): 745-752. DOI: <https://www.doi.org/10.1017/S0007114507750894>
- Crofts TS, Gasparrini AJ, and Dantas G (2017). Next-generation approaches to understand and combat the antibiotic resistome. *Nature Reviews Microbiology*, 15(7): 422-434. DOI: <https://www.doi.org/10.1038/nrmicro.2017.28>
- Cross DE, McDevitt RM, and Acamovic T (2011). Herbs, thyme essential oil and condensed tannin extracts as dietary supplements for broilers, and their effects on performance, digestibility, volatile fatty acids and organoleptic properties. *British Poultry Science*, 52(2): 227-237. DOI: <https://www.doi.org/10.1080/00071668.2011.559454>
- Danladi Y, Loh TC, Foo HL, Akit H, Tamrin NAM, and Azizi MN (2022). Effects of postbiotics and paraprobiotics as replacements for antibiotics on growth performance, carcass characteristics, small intestine histomorphology, immune status and hepatic growth gene expression in broiler chickens. *Animals*, 12(7): 917. DOI: <https://www.doi.org/10.3390/ani12070917>
- Diaz-Sanchez S, Moscoso S, Solís De Los Santos F, Andino A, and Hanning I (2015). Antibiotic use in poultry: A driving force for organic poultry production. *Food Protection Trends*, 35(6): 440-447. Available at: <https://www.foodprotection.org/members/fpt-archive-articles/2015-11-antibiotic-use-in-poultry-a-driving-force-for-organic-poultry-production/>
- Dutta TK, Yadav SK, and Chatterjee A (2019). Antibiotics as feed additives for livestock: Human health concerns. *Indian Journal of Animal Health*, 58(2-SPL): 121. DOI: <https://www.doi.org/10.36062/ijah.58.2spl.2019.121-136>
- El-Sharkawy H, Tahoun A, El-Gohary AEGA, El-Abasy M, El-Khayat F, Gillespie T, Kitade Y, Hafez HM, Neubauer H, and El-Adawy H (2017). Epidemiological, molecular characterization and antibiotic resistance of *Salmonella enterica* serovars isolated from chicken farms in Egypt. *Gut Pathogens*, 9(1): 8. DOI: <https://www.doi.org/10.1186/s13099-017-0157-1>
- Es-Soucratti K, Hammoumi A, Bouchrif B, Asmai R, En-Nassiri H, and Karraouan B (2020). Occurrence and antimicrobial resistance of *Campylobacter jejuni* isolates from poultry in Casablanca-Settat, Morocco. *Italian Journal of Food Safety*, 9(1): 54-59. DOI: <https://www.doi.org/10.4081/ijfs.2020.8692>
- Floch MH (2014). Probiotics and prebiotics. *Advances in Nutrition*, 10(10): 680-681. DOI: [https://www.doi.org/10.1016/s0002-8223\(21\)17552-2](https://www.doi.org/10.1016/s0002-8223(21)17552-2)
- Gahamanyi N, Song DG, Yoon KY, Mboera LEG, Matee MI, Mutangana D et al. (2021). Antimicrobial resistance profiles, virulence genes, and genetic diversity of thermophilic *Campylobacter* species isolated from a layer poultry farm in Korea. *Frontiers in Microbiology*, 12: 622275. DOI: <https://www.doi.org/10.3389/fmicb.2021.622275>
- Gao F, Tu L, Chen Mingliang, Chen H, Zhang X, Zhuang Y, Luo J, and Chen M (2023). Erythromycin resistance of clinical *Campylobacter jejuni* and *Campylobacter coli* in Shanghai, China. *Frontiers in Microbiology*, 14: 1145581. DOI: <https://www.doi.org/10.3389/fmicb.2023.1145581>
- Gong B, Feng Y, Zhuo Z, Song J, Chen X, and Li X (2023). Epidemiological, genetic, and phenotypic characteristics of non-typhoidal *Salmonella* in young children, as obtained from a tertiary hospital in Guangzhou, China. *Microorganisms*, 11(10): 2433. DOI: <https://www.doi.org/10.3390/microorganisms11102433>
- Gouvêa R, Dos Santos FF, De Aquino M, and Pereira VL d A (2015). Fluoroquinolones in industrial poultry production, bacterial resistance and food residues: A review. *Brazilian Journal of Poultry Science*, 17(1): 1-10. DOI: <https://www.doi.org/10.1590/1516-635x17011-10>
- Haag S (2015). FDA industry guidance targeting antibiotics used in livestock will not result in judicious use or reduction in antibiotic-resistant bacteria. *Fordham Environmental Law Review*, 26(2): 313-344. Available at: <https://ir.lawnet.fordham.edu/cgi/viewcontent.cgi?article=1714&context=elr>
- Hashemi SR, Zulkifli I, Bejo MH, Farida A, and Somchit MN (2008). Acute toxicity study and phytochemical screening of selected herbal aqueous extract in broiler chickens. *Faisalabad, ANSInet, Asian Network for Scientific Information*, 4(5): 352-360. DOI: <https://www.doi.org/10.3923/ajp.2008.352.360>

- Halawa EM, Fadel M, Al-Rabia MW, Behairy A, Nough NA, Abdo M, Olga R, Fericean R, Atwa Am, El-Nablaway M et al. (2023). Antibiotic action and resistance: Updated review of mechanisms, spread, influencing factors, and alternative approaches for combating resistance. *Frontiers in Pharmacology*, 14: 1305294. DOI: <https://www.doi.org/10.3389/fphar.2023.1305294>
- Hamed BM, Elenbaawy MI, Mahmoud H, and Ragab E (2023). Investigation of antibiotic resistance pattern and virulence determinants in avian pathogenic *Escherichia coli* isolated from broiler chickens in Egypt. *World's Veterinary Journal*, 13(1): 85-94. DOI: <https://www.doi.org/10.54203/scil.2023.wvj9>
- Hamed DM and Hassan AM (2013). Acids supplementation to drinking water and their effects on Japanese quails experimentally challenged with *Salmonella enteritidis*. *Research in Zoology*, 2013(1): 15-22. DOI: <https://www.doi.org/10.5923/j.zoology.20130301.03>
- Haque AR, Sarker M, Das R, Azad MAK, and Hasan MM (2023). A review on antibiotic residue in foodstuffs from animal source: Global health risk and alternatives. *International Journal of Environmental Analytical Chemistry*, 103(16): 3704-3721. DOI: <https://www.doi.org/10.1080/03067319.2021.1912334>
- Hassan HMA, Mohamed MA, Youssef AW, and Hassan ER (2010). Effect of using organic acids to substitute antibiotic growth promoters on performance and intestinal microflora of broilers. *Asian-Australasian Journal of Animal Sciences*, 23(10): 1348-1353. DOI: <https://www.doi.org/10.5713/ajas.2010.10085>
- Hassan FU, Alagawany M, and Jha R (2022). Editorial: Interplay of nutrition and genomics: Potential for improving performance and health of poultry. *Frontiers in Physiology*, 13: 1030995. DOI: <https://www.doi.org/10.3389/fphys.2022.1030995>
- Hong SS, Jeong J, Lee J, Kim S, Min W, and Myung H (2013). Therapeutic effects of bacteriophages against *Salmonella gallinarum* infection in chickens. *Journal of Microbiology and Biotechnology*, 23(10): 1478-1483. DOI: <https://www.doi.org/10.4014/jmb.1304.04067>
- Hoque R, Ahmed SM, Naher N, Islam MA, Rousham EK, Islam BZ, and Hassan S (2020). Tackling antimicrobial resistance in Bangladesh: A scoping review of policy and practice in human, animal and environment sectors. *PloS One*, 15(1): e0227947. DOI: <https://www.doi.org/10.1371/journal.pone.0227947>
- Jang IS, Ko YH, Kang SY, and Lee CY (2007). Effect of a commercial essential oil on growth performance, digestive enzyme activity and intestinal microflora population in broiler chickens. *Animal Feed Science and Technology*, 134(3-4): 304-315. DOI: <https://www.doi.org/10.1016/j.anifeedsci.2006.06.009>
- Jajere SM (2019). A review of *Salmonella enterica* with particular focus on the pathogenicity and virulence factors, host specificity and adaptation and antimicrobial resistance including multidrug resistance. *Veterinary World*, 12(4): 504-521. DOI: <https://www.doi.org/10.14202/vetworld.2019.504-521>
- Jemaa M Ben, Falleh H, Serairi R, Neves MA, Snoussi M, Isoda H, Nakajima M, and Ksouri R (2018). Nanoencapsulated Thymus capitatus essential oil as natural preservative. *Innovative Food Science and Emerging Technologies*, 45: 92-97. DOI: <https://www.doi.org/10.1016/j.ifset.2017.08.017>
- Kadry M, Nader SM, Dorgham SM, and Kandil MM (2019). Molecular diversity of the *invA* gene obtained from human and egg samples. *Veterinary World*, 12(7): 1033-1038. DOI: <https://www.doi.org/10.14202/vetworld.2019.1033-1038>
- Kapena MS, Muma JB, Mubita CM, and Munyeme M (2020). Antimicrobial resistance of *Escherichia coli* and *Salmonella* in raw retail table eggs in Lusaka, Zambia. *Veterinary World*, 13(11): 2528-2533. DOI: <https://www.doi.org/10.14202/VETWORLD.2020.2528-2533>
- Karakan T, Tuohy KM, and Janssen-van Solingen G (2021). Low-dose lactulose as a prebiotic for improved gut health and enhanced mineral absorption. *Frontiers in Nutrition*, 8: 672925. DOI: <https://www.doi.org/10.3389/fnut.2021.672925>
- Khan JA, Rathore RS, Abulreesh HH, Qais FA, and Ahmad I (2018). Prevalence and antibiotic resistance profiles of *Campylobacter jejuni* isolated from poultry meat and related samples at retail shops in northern India. *Foodborne Pathogens and Disease*, 15(4): 218-225. DOI: <https://www.doi.org/10.1089/fpd.2017.2344>
- Khan SH and Iqbal J (2016). Recent advances in the role of organic acids in poultry nutrition. *Journal of Applied Animal Research*, 44(1): 359-369. DOI: <https://www.doi.org/10.1080/09712119.2015.1079527>
- Kim JH, Kim JW, Lee BB, Lee GI, Lee JH, Kim GB, and Kil DY (2014). Effect of dietary supplementation of bacteriophage on growth performance and cecal bacterial populations in broiler chickens raised in different housing systems. *Livestock Science*, 170: 137-141. DOI: <https://www.doi.org/10.1016/j.livsci.2014.09.005>
- Klein EY, Van Boeckel TP, Martinez EM, Pant S, Gandra S, Levin SA, Goossens H, and Laxminarayan R (2018). Global increase and geographic convergence in antibiotic consumption between 2000 and 2015. *Proceedings of the National Academy of Sciences of the United States of America*, 115(15): E3463-E3470. DOI: <https://www.doi.org/10.1073/pnas.1717295115>
- Kirk MD, Pires SM, Black RE, Caipo M, Crump JA, Devleeschauwer B, Döpfer D, Fazil A, Fischer-Walker CL, Hald T et al. (2015). World health organization estimates of the global and regional disease burden of 22 foodborne bacterial, protozoal, and viral diseases, 2010: A data synthesis. *PLoS Medicine*, 12(12): 1001940. DOI: <https://www.doi.org/10.1371/journal.pmed.1001921>
- Kolida S and Gibson GR (2011). Synbiotics in health and disease. *Annual Review of Food Science and Technology*, 2: 373-393. DOI: <https://www.doi.org/10.1146/annurev-food-022510-133739>
- Kurt T, Wong N, Fowler H, Gay C, Lillehoj H, Plummer P, Scott HM, and Hoelzer K (2019). Strategic priorities for research on antibiotic alternatives in animal agriculture—results from an expert workshop. *Frontiers in Veterinary Science*, 6: 429. DOI: <https://www.doi.org/10.3389/fvets.2019.00429>
- Lee SI, Kim S Do, Park JH, and Yang SJ (2020). Species distribution, antimicrobial resistance, and enterotoxigenicity of non-aureus staphylococci in retail chicken meat. *Antibiotics*, 9(11): 809. DOI: <https://www.doi.org/10.3390/antibiotics9110809>
- Lee S, Kwon T, Chae SJ, Kim JH, Kang YH, Chung GT, Kim W, and Lee DY (2016). Complete genome sequence of bacteriophage MA12, which infects both *Campylobacter jejuni* and *Salmonella enterica* serovar *Enteritidis*. *Genome Announcements*, 4(6): 10-128. DOI: <https://www.doi.org/10.1128/genomeA.00810-16>
- Li Z, Guo Z, Lu X, Ma X, Wang X, Zhang R, Hu X, Wang Y, Pang J, Fan T et al. (2023). Evolution and development of potent monobactam sulfonate candidate IMBZ18g as a dual inhibitor against MDR Gram-negative bacteria producing ESBLs. *Acta Pharmaceutica Sinica B*, 13(7): 3067-3079. DOI: <https://www.doi.org/10.1016/j.apsb.2023.03.002>
- Linh NT, Qui NH, and Triatmojo A (2022). The effect of nano-encapsulated herbal essential oils on poultry's health. *Archives of Razi Institute*, 77(6): 2013-2021. DOI: <https://www.doi.org/10.22092/ARI.2022.358842.2318>
- Lin DM, Koskella B, Lin HC, Lin DM, Lin HC, and Gastroenterology S (2017). Phage therapy: An alternative to antibiotics in the age of multi-drug resistance. *World Journal of Gastrointestinal Pharmacology and Therapeutics*, 8(3): 162-173. DOI: <https://www.doi.org/10.4292/wjgpt.v8.i3.162>
- Ma JL, Zhao Li Hua, Sun DD, Zhang J, Guo YP, Zhang ZQ, Ma QG, Ji C, and Zhao LH (2020). Effects of dietary supplementation of recombinant plectasin on growth performance, intestinal health and innate immunity response in broilers. *Probiotics and Antimicrobial Proteins*, 12(1): 214-223. DOI: <https://www.doi.org/10.1007/s12602-019-9515-2>
- Majewski M, Józefiak A, Kimsa-Furdzik M, Dziubdziała L, Hudak-Nowak M, Wilczyński J, and Anusz K (2021). Antimicrobial resistance of *Escherichia coli* and *klebsiella* spp. Conventionally sampled from factory-farmed chickens—Clinical submissions. *Annals of Agricultural and Environmental Medicine*, 28(2): 271-276. DOI: <https://www.doi.org/10.26444/aaem/120927>
- Marin C, Martín-Maldonado B, Cerdà-Cuéllar M, Sevilla-Navarro S, Lorenzo-Rebenaque L, Montoro-Dasi L, Manzanares A, Ayats T, Mencía-

- Gutiérrez A, Jordá J et al. (2022). Antimicrobial Resistant *Salmonella* in Chelonians: Assessing Its Potential Risk in Zoological Institutions in Spain. *Veterinary Sciences*, 9(6): 246. DOI: <https://www.doi.org/10.3390/vetsci9060264>
- Mehdi Y, Létourneau-Montminy MP, Gaucher M Lou, Chorfi Y, Suresh G, Rouissi T, Brar RK, Côté C, Ramirez AA, and Godbout S (2018). Use of antibiotics in broiler production: Global impacts and alternatives. *Animal Nutrition*, 4(2): 170-178. DOI: <https://www.doi.org/10.1016/j.aninu.2018.03.002>
- Meimandipour A, Emamzadeh AN, and Soleimani A (2017). Effects of nanoencapsulated aloe vera, dill and nettle root extract as feed antibiotic substitutes in broiler chickens. *Archives Animal Breeding*, 60(1): 1-7. DOI: <https://www.doi.org/10.5194/aab-60-1-2017>
- Mohebodini H, Jazi V, Bakhshalinejad R, Shabani A, and Ashayerizadeh A (2019). Effect of dietary resveratrol supplementation on growth performance, immune response, serum biochemical indices, cecal microflora, and intestinal morphology of broiler chickens challenged with *Escherichia coli*. *Livestock Science*, 229: 13-21. DOI: <https://www.doi.org/10.1016/j.livsci.2019.09.008>
- Mountzouris KC and Tsirtsikos P (2009). Prebiotics. *Handbook of dairy foods analysis*. CRC Press, pp. 1-18. Available at: <https://www.taylorfrancis.com/chapters/edit/10.1201/9781420046328-30/prebiotics-mountzouris-tsirtsikos>
- Mthembu TP, Zishiri OT, and El Zowalaty ME (2021). Genomic characterization of antimicrobial resistance in food chain and livestock-associated *Salmonella* species. *Animals*, 11(3): 872. DOI: <https://www.doi.org/10.3390/ani11030872>
- Namdeo S, Baghel R, Nayak S, Khare A, Prakash Pal R, Chaurasiya A, Thakur S, and Reddy BVV (2020). Essential oils: an potential substitute to antibiotics growth promoter in broiler diet. *Journal of Entomology and Zoology Studies*, 8(4): 1643-1649. Available at: <https://www.entomoljournal.com/archives/2020/vol8issue4/PartZ/8-4-178-600.pdf>
- Nagaraja V, Godbole AA, Henderson SR, and Maxwell A (2017). DNA topoisomerase I and DNA gyrase as targets for TB therapy. *Drug Discovery Today*, 22(3): 510-518. DOI: <https://www.doi.org/10.1016/j.drudis.2016.11.006>
- Nazeer N, Uribe-Diaz S, Rodriguez-Lecompte JC, and Ahmed M (2021). Antimicrobial peptides as an alternative to relieve antimicrobial growth promoters in poultry. *British Poultry Science*, 62(5): 672-685. DOI: <https://www.doi.org/10.1080/00071668.2021.1919993>
- Ngai DG, Nyamache AK, and Ombori O (2021). Prevalence and antimicrobial resistance profiles of *Salmonella* species and *Escherichia coli* isolates from poultry feeds in Ruiru Sub-County, Kenya. *BMC Research Notes*, 14(1): 4-9. DOI: <https://www.doi.org/10.1186/s13104-021-05456-4>
- Noor M, Runa NY, Husna A, Rahman MM, Rajib DM, Mahbub-e-Elahi ATM, and Rahman M(2020). Evaluation of the effect of dietary supplementation of bacteriophage on production performance and excreta microflora of commercial broiler and layer chickens in Bangladesh. *MOJ Proteom. Bioinform*, 9(2): 27-31. DOI: <https://www.doi.org/10.15406/mojpb.2020.09.00274>
- Ogundipe FO, Ojo OE, Feßler AT, Hanke D, Awoyomi OJ, Ojo DA, Akintokun AK, Schwarz S, and Maurischat S (2020). Antimicrobial resistance and virulence of methicillin-resistant *staphylococcus aureus* from human, chicken and environmental samples within live bird markets in three Nigerian cities. *Antibiotics*, 9(9): 588. DOI: <https://www.doi.org/10.3390/antibiotics9090588>
- Pirgozliev V, Bravo D, Mirza MW, and Rose SP (2015). Growth performance and endogenous losses of broilers fed wheat-based diets with and without essential oils and xylanase supplementation. *Poultry Science*, 94(6): 1227-1232. DOI: <https://www.doi.org/10.3382/ps/peu017>
- Pirgozliev V, Rose SP, and Ivanova S (2019). Feed additives in poultry nutrition. *Bulgarian Journal of Agricultural Science*, 25: 8-11. Available at: <https://www.agrojournal.org/25/01s-02.pdf>
- Poirel L, Madec JY, Lupo A, Schink AK, Kieffer N, Nordmann P, and Schwarz S (2018). Antimicrobial resistance in *Escherichia coli*. *Microbiology Spectrum*, 6(4): 979-980. DOI: <https://www.doi.org/10.1128/microbiolspec.ARBA-0026-2017>
- Popova T (2017). Effect of probiotics in poultry for improving meat quality. *Current Opinion in Food Science*, 14(17): 72-77. DOI: <https://www.doi.org/10.1016/j.cofs.2017.01.008>
- Pornsukarom S, Van Vliet AHM, and Thakur S (2018). Whole genome sequencing analysis of multiple *Salmonella* serovars provides insights into phylogenetic relatedness, antimicrobial resistance, and virulence markers across humans, food animals and agriculture environmental sources. *BMC Genomics*, 19(1): 801. DOI: <https://www.doi.org/10.1186/s12864-018-5137-4>
- Pourabedin M and Zhao X (2015). Prebiotics and gut microbiota in chickens. *FEMS Microbiology Letters*, 362(15): fnv122. DOI: <https://www.doi.org/10.1093/femsle/fnv122>
- Pugazhendhi A, Michael D, Prakash D, Priyadarshini Krishnamaurthy P, Shanmuganathan R, Abdullah Al-Dhabi N, Duraipandiyar V, Arasu MV, and Kaliannan T (2020). Antibigram and plasmid profiling of beta-lactamase producing multi drug resistant *Staphylococcus aureus* isolated from poultry litter. *Journal of King Saud University Science*, 32(6): 2723-2727. DOI: <https://www.doi.org/10.1016/j.jksus.2020.06.007>
- Pyzik E, Marek A, Stepien-Pyśniak D, Urban-Chmiel R, Jarosz LS, and Jagiełło-Podębska I (2019). Detection of antibiotic resistance and classical enterotoxin genes in coagulase-negative staphylococci isolated from poultry in Poland. *Journal of Veterinary Research*, 63(2): 183-190. DOI: <https://www.doi.org/10.2478/jvetres-2019-0023>
- Rahman MRT, Fliss I, and Biron E (2022). Insights in the development and uses of alternatives to antibiotic growth promoters in poultry and swine production. *Antibiotics*, 11(6): 766. DOI: <https://www.doi.org/10.3390/antibiotics11060766>
- Rao S, Linke L, Magnuson R, Jaunch L, and Hyatt DR (2022). Antimicrobial resistance and genetic diversity of *Staphylococcus aureus* collected from livestock, poultry and humans. *One Health*, 15: 100407. DOI: <https://www.doi.org/10.1016/j.onehlt.2022.100407>
- Ritzi MM, Abdelrahman W, Mohnl M, and Dalloul RA (2014). Effects of probiotics and application methods on performance and response of broiler chickens to an *Eimeria* challenge. *Poultry Science*, 93(11): 2772-2778. DOI: <https://www.doi.org/10.3382/ps.2014-04207>
- Sahu R and Saxena P (2014). Antibiotics in chicken meat. *Pollution monitoring laboratory, India Habitat Centre*. pp. 1-36.
- Salam MA, Al-Amin MY, Salam MT, Pawar JS, Akhter N, Rabaan AA, Alqumber MAA (2023). Antimicrobial Resistance: A Growing Serious Threat for Global Public Health. *Healthcare*, 11(13): 1946. DOI: <https://www.doi.org/10.3390/healthcare11131946>
- Schlee M, Harder J, Köten B, Stange EF, Wehkamp J, and Fellermann K (2008). Probiotic *Lactobacilli* and VSL#3 induce enterocyte β -defensin 2. *Clinical and Experimental Immunology*, 151(3): 528-535. DOI: <https://www.doi.org/10.1111/j.1365-2249.2007.03587.x>
- Scicutella F, Mannelli F, Daghio M, Viti C, and Buccioni A (2021). Polyphenols and organic acids as alternatives to antimicrobials in poultry rearing: A review. *Antibiotics*, 10(8): 1010. DOI: <https://www.doi.org/10.3390/antibiotics10081010>
- Selle PH and Ravindran V (2007). Microbial phytase in poultry nutrition. *Animal Feed Science and Technology*, 135(1-2): 1-41. DOI: <https://www.doi.org/10.1016/j.anifeeds.2006.06.010>
- Shahidi S, Yahyavi M, and Zare DN (2014). Influence of dietary organic acids supplementation on reproductive performance of freshwater angelfish (*Pterophyllum scalare*). *Global Veterinaria*, 13(3): 373-377. Available at: [http://www.idosi.org/gv/gv13\(3\)14/15.pdf](http://www.idosi.org/gv/gv13(3)14/15.pdf)
- Sharma S, ViKaS GalaV, ManiSh AGrawal, Farah naz Faridi, and BrajeSh Kumar and (2017). Multi-drug resistance pattern of bacterial flora obtained from necropsy samples of poultry. *Journal of Animal Health and Production*, 5(4): 165-171. Available at: https://www.nexusacademicpublishers.com/uploads/files/JAHP_5_4_165-171.pdf
- Shree P, Singh CK, Sodhi KK, Surya JN, and Singh DK (2023). Biofilms: Understanding the structure and contribution towards bacterial resistance in antibiotics. *Medicine in Microecology*, 16: 100084. DOI: <https://www.doi.org/10.1016/j.medmic.2023.100084>
- Son JH and Ravindran V (2012). Feed Enzyme Technology: Present status and future developments. *Recent Patents on Food, Nutrition & Agriculture*, 3(2): 102-109. DOI: <https://www.doi.org/10.2174/221279841103020102>

- Syroegin EA, Flemmich L, Klepacki D, Vazquez-Laslop N, Micura R, and Polikanov YS (2022). Structural basis for the context-specific action of the classic peptidyl transferase inhibitor chloramphenicol. *Nature Structural and Molecular Biology*, 29(2): 152-161. DOI: <https://www.doi.org/10.1038/s41594-022-00720-y>
- Tang M, Zhou Q, Zhang X, Zhou S, Zhang J, Tang X, Lu J, and Gao Y (2020). Antibiotic resistance profiles and molecular mechanisms of *Campylobacter* from chicken and pig in China. *Frontiers in Microbiology*, 11: 592496. DOI: <https://www.doi.org/10.3389/fmicb.2020.592496>
- Tillotson G (2018). Discovery, research, and development of new antibiotics: the WHO priority list of antibiotic-resistant bacteria and tuberculosis. *The Lancet Infectious Diseases*, 18(3): 234-236. DOI: [https://www.doi.org/10.1016/S1473-3099\(17\)30754-5](https://www.doi.org/10.1016/S1473-3099(17)30754-5)
- Tolmasy ME (2000). Bacterial resistance to aminoglycosides and beta-lactams: The Tn1331 transposon paradigm. *Frontiers in Bioscience*, 1: 20-29. Available at: <https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=7a655cdad849ce3d34081569387da05e9b6c2649>
- Uddin MB, Hossain SB, Hasan M, Alam MN, Debnath M, Begum R, Roy S, Harun-Al-Rashid A, Chowdhury MS, Rahman MM et al. (2021). Multidrug antimicrobial resistance and molecular detection of MCR-1 gene in *Salmonella* species isolated from chicken. *Animals*, 11(1): 206. DOI: <https://www.doi.org/10.3390/ani11010206>
- Upadhaya SD, Ahn JM, Cho JH, Kim JY, Kang DK, Kim SW, Kim HB, and Kim IH (2021). Bacteriophage cocktail supplementation improves growth performance, gut microbiome and production traits in broiler chickens. *Journal of Animal Science and Biotechnology*, 12(1): 49. DOI: <https://www.doi.org/10.1186/s40104-021-00570-6>
- Vahdatpour T and Babazadeh D (2016). The effects of kefir rich in probiotic administration on serum enzymes and performance in male Japanese quails. *Journal of Animal and Plant Sciences*, 26(1): 34-39. Available at: <https://www.thejaps.org.pk/docs/v-26-01/05.pdf>
- Valenzuela-Grijalva NV, Pinelli-Saavedra A, Muhlia-Almazan A, Domínguez-Díaz D, and González-Ríos H (2017). Dietary inclusion effects of phytochemicals as growth promoters in animal production. *Journal of Animal Science and Technology*, 59(1): 8. DOI: <https://www.doi.org/10.1186/s40781-017-0133-9>
- Van Boeckel TP, Glennon EE, Chen D, Gilbert M, Robinson TP, Grenfell BT, Levin SA, Bonhoeffer S, and Laxminarayan R (2017). Reducing antimicrobial use in food animals. *Science*, 357(6358): 1350-1352. DOI: <https://www.doi.org/10.1126/science.aao1495>
- Varga C, Guerin MT, Brash ML, Slavicek D, Boerlin P, and Susta L (2019). Antimicrobial resistance in fecal *Escherichia coli* and *Salmonella enterica* isolates: A two-year prospective study of small poultry flocks in Ontario, Canada. *BMC Veterinary Research*, 15(1): 464. DOI: <https://www.doi.org/10.1186/s12917-019-2187-z>
- Vikesland P, Garner E, Gupta S, Kang S, Maile-Moskowitz A, and Zhu N (2019). Differential drivers of antimicrobial resistance across the world. *Accounts of Chemical Research*, 52(4): 916-924. DOI: <https://www.doi.org/10.1021/acs.accounts.8b00643>
- Viswanathan M, Pearl DL, Taboada EN, Parmley EJ, Mutschall S, and Jardine CM (2017). Molecular and Statistical Analysis of *Campylobacter* spp. and antimicrobial-resistant *Campylobacter carriage* in wildlife and livestock from Ontario farms. *Zoonoses and Public Health*, 64(3): 194-203. DOI: <https://www.doi.org/10.1111/zph.12295>
- Wang JP, Yoo JS, Lee JH, Zhou TX, Jang HD, Kim HJ, and Kim IH (2009). Effects of phenyllactic acid on production performance, egg quality parameters, and blood characteristics in laying hens. *Journal of Applied Poultry Research*, 18(2): 203-209. DOI: <https://www.doi.org/10.3382/japr.2008-00071>
- Wang S, Zeng X, Yang Q, and Qiao S (2016). Antimicrobial peptides as potential alternatives to antibiotics in food animal industry. *International Journal of Molecular Sciences*, 17(5): 603. DOI: <https://www.doi.org/10.3390/ijms17050603>
- Wang M, Jiang M, Wang Z, Chen R, Zhuge X, and Dai J (2021a). Characterization of antimicrobial resistance in chicken-source phylogroup F *Escherichia coli*: similar populations and resistance spectrums between *E. coli* recovered from chicken colibacillosis tissues and retail raw meats in Eastern China. *Poultry Science*, 100(9): 101370. DOI: <https://www.doi.org/10.1016/j.psj.2021.101370>
- Wang Y, Lyu N, Liu F, Liu WJ, Bi Y, Zhang Z, Ma S, Cao J, Song X, Wang A et al. (2021b). More diversified antibiotic resistance genes in chickens and workers of the live poultry markets. *Environment International*, 153: 106534. DOI: <https://www.doi.org/10.1016/j.envint.2021.106534>
- Wu YB, Ravindran V, Thomas DG, Birtles MJ, and Hendriks WH (2004). Influence of phytase and xylanase, individually or in combination, on performance, apparent metabolisable energy, digestive tract measurements and gut morphology in broilers fed wheat-based diets containing adequate level of phosphorus. *British Poultry Science*, 45(1): 76-84. DOI: <https://www.doi.org/10.1080/00071660410001668897>
- Yang L, Bajinka O, Jarju PO, Tan Y, Taal AM, and Ozdemir G (2021). The varying effects of antibiotics on gut microbiota. *AMB Express*, 11(1): 116. DOI: <https://www.doi.org/10.1186/s13568-021-01274-w>
- Yassin AK, Gong J, Kelly P, Lu G, Guardabassi L, Wei L, Han X, Qiu H, Price S, Cheng D et al. (2017). Antimicrobial resistance in clinical *Escherichia coli* isolates from poultry and livestock, China. *PLoS ONE*, 12(9): e0185326. DOI: <https://www.doi.org/10.1371/journal.pone.0185326>
- Yoneyama H and Katsumata R (2006). Antibiotic resistance in bacteria and its future for novel antibiotic development. *Bioscience, Biotechnology and Biochemistry*, 70(5): 1060-1075. DOI: <https://www.doi.org/10.1271/bbb.70.1060>
- Žbikowska K, Michalczuk M, and Dolka B (2020). The use of bacteriophages in the poultry industry. *Animals*, 10(5): 872. DOI: <https://www.doi.org/10.3390/ani10050872>
- Zhang S, Abbas M, Rehman MU, Huang Y, Zhou R, Gong S, Yang H, Chen S, Wang M, and Cheng A (2020). Dissemination of antibiotic resistance genes (ARGs) via integrons in *Escherichia coli*: A risk to human health. *Environmental Pollution*, 266: 115260. DOI: <https://www.doi.org/10.1016/j.envpol.2020.115260>

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