Sustainable Antibiotic-free Strategies- Current Trends, Challenges and Possibilities in Poultry Farming: A Review

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ABSTRACT

Antibiotics are a class of drugs used to treat bacterial infections. The use of antibiotics in poultry farming is a widespread practice aimed at improving bird health, preventing infections and promoting growth and productivity. However, the excessive and unregulated use of antibiotics in the poultry industry has become a major public health concern due to the increasing risk of antibiotic resistance. The use of antibiotic free strategies is a useful practice aimed at improving poultry health, productivity and welfare of birds by minimizing and eliminating use of antibiotics. These approaches include the use of probiotics, prebiotics, organic acids, synbiotics, feed enzymes, vitamins and minerals, vaccines, antimicrobial peptides, phytobiotics and immunomodulators as alternatives to conventional antibiotics.

Key words: Antibiotic resistance, Organic acid, Phytobiotics, Prebiotics, Probiotics.

Antimicrobial resistance (AMR) has emerged as a major threat to global public health and sustainable development. According to recent estimates, bacterial AMR directly caused approximately 1.27 million deaths worldwide in 2019 and was associated with nearly 4.95 million deaths overall. The excessive and inappropriate use of antimicrobial agents in human healthcare, animal husbandry and agriculture is considered a primary factor contributing to the rise of drug-resistant microorganisms. Beyond its impact on mortality and morbidity, AMR also imposes a considerable economic burden. The World Bank projects that by 2050, AMR may lead to an additional US$ 1 trillion in healthcare expenditures, while annual global gross domestic product (GDP) losses could range from US$ 1 trillion to US$ 3.4 trillion by 2030 (World Health Organization, 2023).

At the 79th UN general assembly high-level Meeting on AMR, held on September 26, 2024, in New York under the theme "Investing in the present and securing our future together: Accelerating multi-sectoral global, regional and national actions to address antimicrobial resistance", world leaders endorsed a political declaration with firm targets. These include slashing the estimated 4.95 million annual human deaths tied to bacterial AMR by 10% by 2030, ensuring 70% of global antibiotics come from low-AMR-risk categories and strengthening surveillance of antimicrobial use and resistance across sectors. Meanwhile, FAO, WHO, UNEP and WOAH pledged support through a One Health approach, providing guidance and monitoring *via* an updated global AMR action plan by 2026.

Highlights

- This article will serve as a valuable source of information for the antibiotic resistance in poultry industry.
- This article will help to study the alternative strategies for the antibiotic resistance in poultry farming.
- It will give significant insight of healthy poultry production and animal welfare.
- This article will help promote public health by reducing the dependence on antibiotics in poultry production.

Antibiotics and it's use in poultry farming

Antibiotics serve as medications specifically designed to treat and prevent bacterial infections. Antibiotics have a number of uses in poultry farming, including:

1. For growth promotion-sub therapeutic doses (Most commonly used).
2. For disease prevention (Prophylaxis).
3. For disease treatment (Muhammad *et al*., 2020).

A study by the Centre for Science and Environment (CSE) found that common antibiotics used in poultry farming are oxytetracycline, tetracycline, chlortetracycline and doxycycline, which are all tetracyclines; Enrofloxacin and ciprofloxacin are fluoroquinolones and neomycin is an aminoglycoside (Sahu and Saxena, 2014).

Antibiotic resistance

According to the World Health Organization (WHO), antibiotic resistance refers to the capacity of bacterial

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populations to withstand the effects of antimicrobial agents even at inhibitory concentrations. The transmission of resistant bacteria from poultry products to humans can potentially occur through the handling or consumption of meat contaminated with pathogenic microorganisms.

The global demand for poultry meat has been steadily rising, leading to continuous expansion of the poultry industry (Jabbar and Rehman, 2023; Shahbazi *et al*., 2022). Poultry meat and eggs are considered cost-effective protein sources, providing a higher proportion of protein per unit of human consumption compared to cow milk, mutton, pork and beef (Otte and Pica-Ciamarra, 2010). Despite these nutritional and economic advantages, recent studies reporting the presence of antibiotics and other xenobiotic residues in meat products have raised concerns regarding the perception of poultry meat as a safe and healthy food source (Sahu and Saxena, 2014); (Raghav *et al.,* 2022).

Current estimates indicate that antibiotic-resistant bacteria (ARB) are associated with approximately 700,000 deaths worldwide annually and this figure is projected to rise to nearly 10 million deaths per year by 2050 (Vikesland *et al*., 2017). Recent evidence also suggests that resistant bacteria may be transmitted from mothers to newborns, potentially resulting in neonatal sepsis, which remains a leading cause of infant mortality in low- and middle-income countries (Carvalho *et al*., 2022). Consequently, monitoring antibiotic residues in foods derived from animals is essential for ensuring food safety and supporting the principles of the “One Health” approach aimed at protecting both human and animal health.

Case study on the detection of antibiotic residues in poultry in Chhattisgarh

The presence of antibiotic residues in chicken meat represents a potential risk to consumer health and can also have adverse economic implications for the poultry sector, including restrictions on exports.

A study was designed to evaluate the occurrence of antibiotic residues in retail chicken meat collected from different agro-climatic regions of Chhattisgarh, India and to estimate associated human health risks using monte carlo simulation. A total of 336 chicken meat samples were analyzed, out of which 147 samples (43.7%) tested positive for antibiotic residues, while 60 samples (17.8%) exceeded the maximum residue limits (MRLs).

Research on elevated antimicrobial resistance (AMR) in poultry farm environments in Tamil Nadu and Andhra Pradesh (Chandrakar *et al*., 2023)

In this study, researchers from the NGOs Toxics Link and World Animal Protection collected a total of 14 samples of poultry litter and groundwater from six poultry farms. Out of these, 11 samples showed a concerning presence of antimicrobial resistance genes (ARGs) associated with 15 clinically important antibiotics, including glycopeptides and macrolides.

The findings were linked to widespread and often indiscriminate use of antibiotics by poultry farmers, largely driven by limited awareness of their consequences, as reported in surveys conducted by Toxics Link. Although the Bureau of Indian Standards has advised against the use of antibiotic growth promoters (AGPs) in poultry feed, these substances are still available in the market and continue to be used in poultry production.

Furthermore, colistin-an antibiotic considered a last-resort treatment for multidrug-resistant infections and banned for use in food-producing animals by the Union Ministry of Health in 2019-remains accessible for sale through online platforms.

India contributes approximately 3% of the worldwide use of antimicrobials in food-producing animals. With the country increasingly intensifying livestock and poultry production to address food security challenges, concerns are rising that the poultry sector may become a significant hotspot for the emergence and spread of antimicrobial resistance.

According to the World Health Organization (WHO), drug-resistant infections are responsible for at least 700,000 deaths annually, including over 200,000 deaths caused by multidrug-resistant tuberculosis.

Causes of antibiotic resistance

Antibiotic resistance is driven by several factors, including insufficient awareness, excessive and inappropriate use of antibiotics, their application as growth promoters, lack of regulatory control, low cost and easy availability.

When antibiotics are administered to food-producing animals at sub-therapeutic levels, susceptible bacteria are eliminated, while those with resistant traits survive. These resistant organisms then multiply and gradually dominate the microbial population. Resistance can further spread through genetic mutations or plasmid-mediated gene transfer, allowing resistant traits to be passed on to future generations as well as to other bacterial species (Catry *et al*., 2003).

Humans may be exposed to resistant bacteria through the handling or consumption of contaminated meat products (Van den Bogaard and Stobberingh, 2000). After entering the body, these bacteria can colonize the gastrointestinal tract and transfer resistance genes to other members of the normal gut microbiota, thereby complicating the effective treatment of bacterial infections (Stanton, 2013).

In intensive poultry production systems, antibiotics are commonly applied in several ways, including incorporation of low-dose antibiotics in feed, therapeutic use for treating infections and prophylactic use for disease prevention.

This leads to formation of Antibiotics resistant bacteria in poultry which then passes on to human beings through consumption of eggs and meat. Also, these antibiotics are passed into the faeces and litter material through which it reaches to surface water which further contaminates crops, vegetables and fruits. Through this indirect way they again reach to human beings. Antibiotics resistant bacteria are also transferred to poultry farmers during handling (Kumar *et al*., 2019).

Aim and objectives

This review aims to critically assess the current patterns of antibiotic usage and the status of antimicrobial resistance in poultry production systems. It further explores the effectiveness, underlying mechanisms, benefits and limitations of antibiotic-free alternatives. In addition, the review discusses the practical challenges associated with their implementation in field conditions and outlines future directions for achieving sustainable poultry production within a One Health approach.

Methodology

This review was carried out to compile and analyze existing evidence on antibiotic usage, antimicrobial resistance and antibiotic-free alternatives in poultry production. A systematic and comprehensive search of the literature was conducted using major electronic databases, including PubMed, Scopus, Google Scholar and Web of Science.

Peer-reviewed journal articles, reports from international agencies and relevant review papers published from 2000 to 2024 were included in the analysis. The search strategy incorporated keywords such as "antibiotic resistance in poultry," "antibiotic alternatives," "poultry probiotics," "phytobiotics," "organic acids" and "bacteriophages in poultry production."

Studies addressing poultry health, production performance, food safety and strategies for mitigating antimicrobial resistance were considered, whereas non-English publications and studies not relevant to the topic were excluded. The selected literature was then critically evaluated and synthesized to present a comprehensive overview of antibiotic-free approaches in poultry farming.

Antibiotic-free strategies

Opportunities in antibiotic-free production

Antibiotic-free poultry production offers several advantages across the production chain. For consumers, it ensures improved food quality and safety. For producers, it supports optimal performance and healthier poultry flocks. From an animal welfare perspective, it promotes better health outcomes and contributes to long-term sustainability in poultry farming.

Characteristics of an ideal alternative

An effective substitute for antibiotics should meet several important criteria. It should not promote antimicrobial resistance or disrupt the normal gut microflora. It must not reduce feed palatability and should be capable of inhibiting or eliminating pathogenic microorganisms. Additionally, it should be non-toxic and free from adverse effects on birds.

The ideal alternative should also be environmentally safe, easily degradable and stable within feed and the gastrointestinal tract. It should enhance growth performance and feed conversion efficiency while being easily eliminated from the body or leaving only minimal short-term residues.

Alternative strategies to antibiotics (antibiotic-free approaches)

1). Probiotics

According to the Food and Agriculture Organization of the United Nations (FAO), probiotics are defined as live microorganisms which, when administered in adequate amounts, provide health benefits to the host. Common probiotic organisms include *Lactobacillus, Streptococcus,* Enterococcus, *Bacillus*, *Clostridium*, *Bifidobacterium* species and *Escherichia coli*. In addition, yeast and fungal strains such as Saccharomyces cerevisiae and Aspergillus oryzae are also utilized as probiotic agents.

Advantages of probiotics

Probiotics contribute to improved gut health, reduce the spread of infections and mortality and enhance feed conversion efficiency. They also support better weight gain and growth rates in poultry. Furthermore, they stimulate digestive enzyme activity, improving nutrient absorption and enhance vaccine efficacy. Probiotics assist in the rapid detoxification of mycotoxins and leave no harmful residues in animal products.

Benefits of probiotics

Probiotics help in modulating the gut microbiota by establishing a healthy intestinal microbial balance (Dhama *et al*., 2008). They also act through competitive exclusion by occupying binding sites in the gastrointestinal tract and producing antimicrobial substances that inhibit pathogen growth.

In addition, probiotics produce antimicrobial compounds such as bacteriocins, which are effective against pathogens including *Clostridium perfringens*, *Salmonella*, *Campylobacter* and *Escherichia coli*. They also enhance immune responses by increasing immunoglobulin production, activating macrophages and lymphocytes and stimulating interferon production (Yang, 2009).

Moreover, probiotics strengthen intestinal barrier function by adhering to the gut mucosa, thereby forming a protective barrier against pathogen invasion and contributing to improved overall immunity.

2). Prebiotics

Prebiotics are non-digestible feed components that benefit the host by selectively stimulating the growth and/or activity of a limited number of beneficial bacteria in the colon, thereby improving gut health by serving as a nutrient source for these microorganisms in the gastrointestinal tract.

Commonly used prebiotics include

Gluco-oligosaccharides (GOS), which are found in legumes and dairy products; fructo-oligosaccharides (FOS), present in fruits, vegetables and cereals;

mannan-oligosaccharides (MOS), derived from yeast and certain plants; stachyose and oligochitosan (Jiang *et al*., 2006).

Functions of prebiotics

Prebiotics help modify the gastrointestinal microflora by encouraging the growth of beneficial bacteria such as *Lactobacillus* and *Bifidobacterium*. They also stimulate immune responses, reduce the risk of pathogen invasion and colon cancer and improve gut health by enhancing enzymatic activity in the digestive system. In addition, their use can ultimately contribute to reduced production costs (Peric *et al*., 2009).

3). Synbiotics

Synbiotics are formulations that combine probiotics and prebiotics, designed to improve the survival and activity of beneficial microorganisms within the gastrointestinal tract (GIT), thereby promoting overall gut health. Commonly used synbiotic combinations include lactitol with *Lactobacillus* species, as well as fructo-oligosaccharides (FOS) with *Bifidobacterium* species (Yang *et al*., 2009). In general, synbiotics involve the use of prebiotics to support and enhance the growth of probiotic organisms.

4). Function

Synbiotics promote growth performance in broiler chickens by improving intestinal structure and enhancing nutrient absorption, which ultimately leads to better overall production efficiency (Awad *et al*., 2008; Hassanpour *et al*., 2013).

Organic acids

Historically, organic acids have been utilized as natural food preservatives and hygiene enhancers due to their ability to inhibit microbial growth and improve the freshness and shelf life of food products (Sadarao *et al*., 2025). Their antimicrobial properties also make them effective alternatives to antibiotic growth promoters in poultry production. Organic acids are weak acids that can suppress or prevent the proliferation and colonization of pathogenic bacteria in the intestinal tract of birds.

Functions of organic acids

Organic acids exhibit broad antibacterial activity against various pathogenic microorganisms. They can penetrate bacterial cell walls and, once inside the cell, dissociate into their conjugate base forms, leading to a reduction in intracellular pH. This acidic internal environment disrupts cellular functions and inhibits bacterial growth (Mani-Lopez *et al*., 2012).

Additionally, organic acids help lower gut pH and enhance nutrient utilization in poultry diets.

Examples of organic acids

Sorbic acid disrupts membrane proteins and increases bacterial cell permeability (Abdelrahman, 2016). Propionic acid is effective in inhibiting feed-borne molds and preventing mycotoxin production (Zha and Cohen, 2014). Oxalic acid, commonly found in plant sources, can influence calcium availability, particularly in laying hens (Jadhav *et al*., 2015).

Benefits of organic acids

Organic acids reduce pathogen colonization along the intestinal lining, thereby protecting epithelial cells. They also promote epithelial cell proliferation, accelerate intestinal healing, improve villus height and enhance nutrient absorption capacity. These properties make organic acids useful in reducing microbial loads, including pathogens such as *Salmonella* and *Escherichia coli*.

5). Feed enzymes, vitamins and minerals

Feed enzymes are added to poultry diets to break down complex feed components such as phytate, xylan and other non-starch polysaccharides. This enhances nutrient availability, improves feed digestibility and supports better growth performance and gut health. Commonly used enzymes include phytase, xylanase and other glycanase complexes.

Phytase is the most widely used single enzyme, which hydrolyzes phytate into inositol and inorganic phosphate. This process releases phosphorus from cereal grains, allowing more efficient utilization of this essential and costly mineral in poultry nutrition. In addition, enzymes that degrade fiber and starch, such as xylanase and β-glucanase, improve feed conversion ratio, nutrient absorption, growth performance and also help reduce issues like wet litter.

Benefits of enzymes

Feed enzymes support overall health and growth, improve nutrient utilization and help reduce feed costs in poultry production.

6). Vitamins and minerals

Vitamins are organic micronutrients required for essential physiological functions such as immune response, energy metabolism and cellular repair. Minerals, on the other hand, are inorganic elements that support key biological processes including bone formation, fluid balance and muscle function. Together, vitamins and minerals play a significant role in improving feed efficiency, immune status and overall productivity in poultry.

Important vitamins and their functions

Vitamin C acts as an antioxidant, helps reduce heat stress (particularly during summer conditions), enhances feed intake and improves metabolic efficiency (Sahin *et al*., 2003). Vitamin E supports better feed conversion ratio, growth performance and overall productivity in poultry. Vitamins A and D are important for strengthening immunity and promoting growth. The B-complex vitamins contribute to improved digestibility, nutrient utilization, growth and overall performance.

Important minerals and their functions

Calcium and phosphorus are essential for proper growth and skeletal development. Zinc and selenium function as antioxidants, helping to reduce stress while enhancing immune response and disease resistance. Magnesium plays a role in muscle development and function. Other essential minerals include sodium, potassium, iron, copper, manganese and iodine, all of which contribute to various metabolic and physiological processes necessary for healthy poultry growth and production.

7). Antimicrobial peptides (AMPs)

Antimicrobial peptides, also referred to as host defense peptides, are short amino acid chains typically consisting of around 30-60 residues and are present in all forms of living organisms. These peptides exhibit both antimicrobial and immunomodulatory activities and can act against bacteria, fungi and viruses primarily by targeting and disrupting microbial cell membranes (Li *et al*., 2012; Parachin *et al.,* 2012).

AMPs have been shown to enhance growth performance, stimulate immune cell activity, improve intestinal structure and increase beneficial gut microbiota populations such as *Lactobacillus* spp. (Daneshmand *et al.,* 2019). Due to these properties, they are considered promising natural feed additives capable of replacing therapeutic antibiotics and antibiotic growth promoters in poultry production, with potential to help control antimicrobial-resistant strains within flocks.

Since most AMPs act by targeting pathogen cell membranes, the likelihood of resistance development is relatively low, as structural changes in microbial membranes occur slowly over evolutionary time (Lee *et al.,* 2016).

Experimental in vitro studies have also demonstrated that peptides derived from chicken leukocytes significantly inhibit the growth of *Candida albicans*, *Escherichia coli* and *Listeria monocytogenes* (Harwig *et al*., 1994).

8). Phytobiotics

Phytobiotics are bioactive compounds derived from plants that are incorporated into animal feed to enhance health and promote growth. These substances consist of plant secondary metabolites such as phenols, flavonoids, tannins, saponins and essential oils. They are widely used as natural alternatives to antibiotic growth promoters, particularly in monogastric animals such as poultry and pigs (Khaksar *et al*., 2012; Karangiya *et al*., 2016). Phytobiotics possess a range of biological activities, including antibacterial, antiviral, antifungal and antiprotozoal effects.

Benefits of phytobiotics

Growth promotion

Supplementation with plant-based additives such as garlic at around 3% has been shown to improve growth performance in broiler chickens (Elagib *et al*., 2013). Other spices, including black pepper and cinnamon, also contribute to enhanced growth in poultry.

Antimicrobial effects

Tannins exhibit strong anticoccidial activity in chickens. Garlic, through its active compound allicin, can penetrate bacterial cell membranes and interfere with essential enzymes, thereby disrupting microbial cellular processes.

Antioxidant activity

Turmeric is widely recognized for its antioxidant properties.

Improved feed efficiency

Essential oils stimulate the secretion of digestive enzymes from the pancreas and liver, including trypsin, amylase and bile, which enhances feed digestibility and overall feed efficiency (Gopi *et al*., 2014).

Immunomodulatory effects

Various plant-derived compounds such as neem, ashwagandha, flavonoids, lectins, polysaccharides, peptides, tannins and garlic contribute to improved immune responses in poultry.

9). Immunomodulators

Immunomodulators, also known as immunostimulants, are substances that regulate or modify the immune system's response to improve disease resistance and overall immunity. These compounds include a wide range of natural and synthetic agents.

Types of immunomodulators include

1. Mineral-based compounds such as selenium and zinc.
2. Vitamins including A, E and C.
3. Amino acids such as arginine and leucine.
4. Plant-derived polysaccharides like astragalus polysaccharide and algal polysaccharides.
5. Oligosaccharides including mannan oligosaccharides and fructo-oligosaccharides.
6. Microbial preparations such as BCG vaccine and *Lactobacillus* species.
7. Bacterial extracts including β-glucans, peptidoglycan and lipopolysaccharides.
8. Biological molecules (cytokines) such as interferons, transfer factors, interleukins and immunoglobulins.

These immunomodulatory agents play an important role in enhancing immune function and improving resistance to infections in poultry production systems.

10). Vaccines as alternatives to antibiotics

Vaccination represents an important alternative strategy to antibiotics in poultry production by providing a preventive approach for controlling infectious diseases without contributing to antimicrobial resistance. Vaccines offer protection against specific pathogens, thereby decreasing the reliance on antibiotic treatments and supporting improved growth performance and flock health.

Benefits of vaccines

Vaccines provide preventive protection against disease outbreaks, reduce the development and spread of antibiotic resistance, enable targeted control of specific infections and improve overall animal welfare.

Common poultry vaccines are available for:

- Marek's disease.
- Newcastle disease (Ranikhet disease).
- Infectious bursal disease (IBD/gumboro disease).
- Infectious bronchitis.

11). Bacteriophages, endolysins and lysozymes

Bacteriophages are highly specific viruses that infect and destroy bacteria by producing enzymes known as endolysins, which ultimately lead to bacterial cell lysis. They are considered safe alternatives to antibiotics because they do not affect animal or plant cells. Although bacteriophages are unlikely to fully replace antibiotics, they hold significant potential in managing infections caused by multidrug-resistant bacteria.

Endolysins and lysozymes are types of hydrolytic enzymes derived from various sources, including bacteriophages, animals, plants, bacteria and insects and they differ in their specificity toward target bacteria. These enzymes break down peptidoglycan, a key structural component of the bacterial cell wall, resulting in bacterial cell destruction.

Comparative evaluation and field challenges

Although a variety of antibiotic alternatives have demonstrated encouraging outcomes, their overall effectiveness is often influenced by farm management practices, environmental conditions and the genetic background of the birds.

Probiotics and prebiotics are known to enhance gut health and immune function; however, their performance may be inconsistent due to strain-specific effects and issues related to storage stability. Organic acids are effective in reducing enteric pathogens, but their efficiency can vary depending on diet composition and the buffering capacity of feed.

Phytobiotics provide antimicrobial and antioxidant benefits, yet challenges such as variability in plant constituents and lack of standardized dosing limit their consistent application. Antimicrobial peptides and bacteriophages offer high target specificity and a low risk of resistance development; nevertheless, their large-scale commercial use is constrained by production costs and limited regulatory approval.

Vaccination remains the most dependable preventive strategy, but it cannot fully substitute antibiotics in situations where farm hygiene, management and biosecurity practices are inadequate. Therefore, a comprehensive approach combining nutrition, vaccination, biosecurity and effective management is essential for successful antibiotic-free poultry production.

Integrated approach

Evidence indicates that no single alternative is sufficient to completely replace antibiotics across all poultry production systems. Instead, an integrated strategy that combines feed additives, improved housing conditions, strict hygiene, vaccination programs and precision nutrition offers the most sustainable way to reduce antimicrobial use while maintaining productivity.

CONCLUSION

The growing global concern over antimicrobial resistance highlights the urgent need to shift toward antibiotic-free poultry production systems. Various alternatives such as probiotics, phytobiotics, organic acids and vaccines show considerable potential in supporting gut health, immunity and overall performance.

However, differences in efficacy, economic constraints and practical challenges in field implementation limit their widespread adoption. Future research should focus on optimizing combination strategies, exploring host-microbiome interactions and developing cost-effective delivery methods.

In addition, stronger farm management practices and supportive policy frameworks will be crucial for the successful implementation of antibiotic-free systems. This transition is essential for promoting sustainable poultry production and improving public health outcomes within a One Health framework.

Author's contribution

Sakshi Rathore wrote the article under the guidance of Rajni Arora .

Conflict of interest

The authors declare that there are no conflicts of interest associated with this study.

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