Review Article

Growth Performance and Meat Attributes of Poultry in Response to Dietary Probiotic Supplementation: A Review

Teedzai Chitura*

Department of Animal Science, University of Venda, Private Bag X5050, Thohoyandou 0950 , South Africa.

Abstract | The emergence of drug-resistant microorganisms threatens human and animal health. The inappropriate use of prescribed antibiotics as growth promoters in livestock production is the main contributor of antimicrobial resistance. As a result, there have been growing calls by consumers and international health organizations for reduced application of antibiotic growth promoters in livestock production. To address this problem, several animal feed commissioners and summits have legislated and banned the use of antibiotic growth promoters in livestock feeds. Given these scenarios, animal nutritionists embarked on the quest for the search of alternative and sustainable growth promoters, as a replacement for antibiotics. The application of probiotics in poultry production appears to be an economically feasible alternative. Hence, the present review aims to provide comprehensive information regarding the use of probiotics as a management tool for improving poultry performance while ensuring the production of safe meat and other poultry products. It was hypothesized that probiotic supplementation can successfully replace the use of antibiotics as growth promoters in poultry diets without causing adverse effects on growth performance and products quality. A literature search was conducted to cover the scope of growth performance and meat attributes of poultry species fed diets supplemented with probiotics. The search process was conducted with the use of electronic databases such as Science Direct, Google scholar, JURN, Directory of Open Access Journals, and Research gate. The keywords were "antibiotics', "growth performance", "meat quality", "poultry", and "probiotics". The objective of this review study was to provide a comprehensive understanding of the application of probiotics in poultry production as antibiotic alternatives for improving the growth performance of birds . Overall, results have shown that incorporating probiotics in poultry diets or drinking water improves productivity without adversely affecting the quality and sensory attributes of poultry meat.

Keywords | Food safety, Growth performance, Poultry, Probiotics, Sensory attributes

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***Correspondence** | Teedzai Chitura, Department of Animal Science, University of Venda, Private Bag X5050, Thohoyandou 0950 , South Africa.; **Email:** teedzai.chitura@ul.ac.za
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INTRODUCTION

Poultry products contribute to global food security as well as address the challenges of malnutrition faced by many marginalized households in developing countries (WHO, 2018). However, the expansion of poultry industries is threatened by factors such as a lack of improved chicken breeds, low planes of nutrition, and the high occurrence of diseases (Malematja *et al*., 2022). Over the years, antibiotic growth promoters have found use in poultry production for optimal gut health, reducing the effects of pathogens as well as enhancing growth performances

(Sapsuha *et al*., 2021; Malematja *et al*., 2023). However, negative effects on human health due to the emergence of drug-resistance microorganisms are associated with the indiscriminate application of antibiotics in poultry farming (WHO, 2018; Peralta-Sánchez *et al*., 2019). In light of these challenges, alternative production systems that limit reliance on antibiotics are being explored. Probiotics are alternatives for improving gut health (Ricke and Rothrock, 2020) and optimal growth performance in birds (Krysiak *et al*., 2021) which according to Peralta-Sánchez *et al*. (2019) are the key attributes that alternatives to antibiotics should have. World Health Organization (2018) defined probiotics as living microorganisms supplemented to livestock to modulate gut health and maintain intestinal microflora colonizing the gut and subsequently improving performance of the host animal. Krysiak *et al*. (2021) defined probiotics as universal feed additives that can be incorporated into poultry diets with other feed additives. Probiotics are usually produced in the feed industry laboratories through the process of isolating and selecting desired microorganisms, cultivating, and fermenting, and used as feed additives in manufacturing feeds (Zhang *et al*., 2021).

Though there are many probiotic species registered for use in animal feeds, species such *Lactobacillus*, *Lactococcus*, *Saccharomyces*, and *Bifidobacterium* are commonly used in poultry feeds (Jha *et al*., 2020). Probiotics advance the growth performance by modulating the microbial community of the gut, hence promoting the development of the gastrointestinal tract and enhancing the overall health and performance of the bird (Malematja *et al*., 2022). The context of probiotic supplementation in livestock production is widely investigated. Several bodies of literature have reported enormous benefits of probiotic supplementation in poultry production, including improved gut health and general health condition, enhanced growth performance through improved feed conversion ratio, increase in growth rate and weight gain, and a reduction in mortality rates (Zhang *et al*., 2016, 2021). Some studies reported positive effects of probiotics in poultry production including their beneficial effects on carcass composition (Getabalew *et al*., 2020). Yang *et al*. (2010) reported improved tenderness when the probiotic *C. butyricum* was included in a diet. Furthermore, Peralta-Sánchez *et al*. (2019) reported increased egg production in hens supplemented with probiotics. Bacteria are popular probiotic microorganisms used in poultry production (Peralta-Sánchez *et al*., 2019). Although probiotics have proven to be effective in replacing prescribed antibiotic growth promoters in feeds, previous studies recommended further investigations on comparative studies, recommended dosages and methods of administration, and optimal ages for probiotic supplementation. The present review provides an overview of the application of probiotics in poultry production as antibiotic alternatives for improving the growth performance of birds and ensuring that poultry products are free from antibiotic residues and therefore safe for human consumption.

Literature search strategy

The literature search was conducted by accessing data from electronic database sources such as the Directory of Open Access Journals (DOAJ), Research Gate, Science Direct, Scopus, and Google Scholar. This review mainly focuses on the potential of probiotics in substituting synthetic growth promoters in poultry production in the context of an increasingly global human population that places a huge demand for poultry and other animal products. Furthermore, the search process was extended to cover the role played by probiotic supplementations on growth performance and meat quality in poultry production systems. Databases were accessed using several keywords which were paraphrased in different search engines. The keywords alternative growth promoter, antibiotics, meat quality, natural growth promoter, poultry, and probiotics were used in the search engines.

Challenges associated with the use of antibiotics and the potential use of probiotics in poultry production

Poultry meat has unsaturated fatty acids, oleic acid, and linoleic acids which reduce cholesterol as well as lower lipoproteins which are not desirable as they threaten human health (Zhang *et al*., 2021). Given these positive attributes, poultry industries are rapidly expanding along with the rising demand for poultry meat (Ghosh *et al*., 2019). The indiscriminate use of antibiotics as growth promoters in poultry production leads to serious consequences such as antimicrobial resistance in animals and drug residues in poultry products (Figure 1) which threatens global food safety and security (Zhang *et al*., 2021). As a result, the European Union (livestock production under Council Regulation (EC) No 2821/98) and several similar other organizations legislated and imposed restrictions on the use of antibiotics as growth promoters in animal feeds (Laxminarayan *et al*., 2015; Salim *et al*., 2018). Consequently, there is an upsurge in interest in selecting alternative growth promoters as a replacement for synthetic growth promoters (Krysiak *et al*., 2021; Zhang *et al*., 2021). Poonam and Srivastav *et al*. (2021) reported that the search for alternative growth promoters led to the identification of bacterial strains as a replacement for antibiotic growth promoters due to their desirable properties. The use of probiotics has proven to be important in improving the immune response thereby improving the overall performance of the host animal (Figure 1). Peralta-Sánchez *et al*. (2019) reported that since the discovery of the positive effects of probiotics in livestock production decades ago, bacterial species similar to those already existing in the gut of animals found common use in improving gut health and conditions by modulating intestinal microbiota. Some explanations were brought forward on how probiotics can influence gut health, animal welfare, and growth performances of the host animals (Figure 1). According to Salim *et al.* (2018), as antimicrobial agents, probiotics reduce pathogenic microbes population in the gut, aiding the digestion of feed. The second mechanism proposed by the same authors is that of modulation of the immune system response through elevated antibody titers. Krysiak *et al.* (2021) cited the mechanism of competitive exclusion, which involves the formation of a mucus attachment on the intestinal epithelial layer.

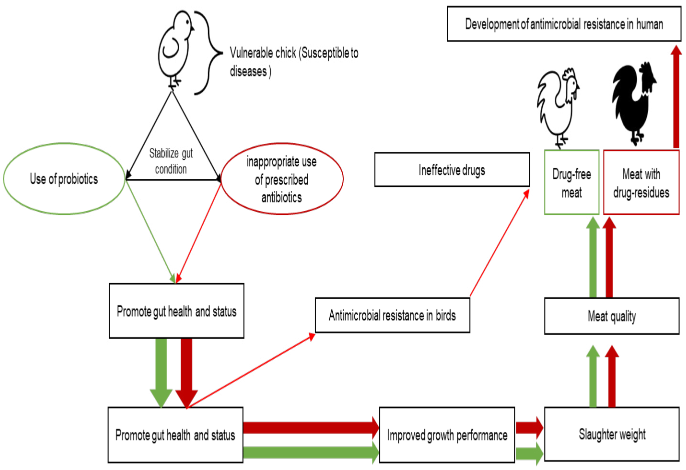

Figure 1: Challenges associated with the use of prescribed antibiotics and the potential use of probiotics to optimize poultry productivity in the context of increasing global human population growth and the health issues related to the development of antimicrobial resistance in humans and animals.

Probiotics are among the most effective methods of microbial control with no harm to the environment (Hejdysz *et al.*, 2012). Multiple works of literature have proven in many ways that the use of probiotics has diverse benefits to the poultry meat industry and thus the prospect of using probiotics in poultry production is gathering momentum worldwide. However, the efficiency of probiotics vary with the species used and practical applications (Salim *et al.*, 2018).

Utilization of probiotics in free-range and pasture-based poultry production systems

Natural poultry-rearing systems are gaining popularity as chickens are raised on organic feeds, which are preferred by a growing population of consumers globally (Shi *et al.*, 2019). Natural rearing systems can either be free-range or pasture-based. Ricke and Rothrock (2020) cited some of the concerns regarding natural poultry rearing systems such as increased exposure of chickens to various pathogenic organisms and the fact that the birds have to rely solely on their natural defense mechanisms to combat pathogens. The same authors also indicated that the risk of salmonellosis is high in natural rearing systems. Exposure to harsh environments, provision of low-quality feedstuffs, and high mortality rates are some of the challenges of natural poultry rearing systems. According to Shi *et al.* (2019), given these challenges, the use of feed additives such as organic acids, medicinal oil extracts, probiotics, and prebiotics becomes key to ensure healthy and productive chicken flocks. Ricke and Rothrock (2020) observed improved growth performance and egg production following the use of probiotics while Khan and Chousalkar (2021) observed that probiotics could be used to control foodborne pathogens and ensure food safety. El-Jeni *et al.* (2021) reported that administration of probiotics to day-old-chicks could improve health conditions of free-range chickens by limiting the proliferation of foodborne pathogens as well as the colonization of the gut by pathogens thereby preventing the occurrence of diseases that threaten the health and production performance of free-range or pasture-raised chicken flocks.

Application of probiotics as a managerial tool for growth performance in large-scale or intensive production systems

Factors such as as genetic make-up, age, nutrition, health condtion, and sex have a significant effect on the growth performance of an animal (Al-Shawi *et al.*, 2020). Gut microbial populations also play a crucial role by aiding the process of digestion and immune system development (Zhang *et al.*, 2011). A balanced proportion between the beneficial and harmful microbial populations enhances nutrient digestibility resulting in improved growth performance (Jerzsele *et al.*, 2012). Maintaining and stabilizing poultry gut conditions in large-scale productions with probiotics is inevitable (Atela *et al.*, 2019). Colonization of the digestive tract with probiotics could induce nutrient utilization, which could result in improved growth traits of the host animal (Qorbanpour *et al.*, 2018; Zhang *et al.*, 2021). Furthermore, probiotic administration is said to modulate the gut microbial community and improve physiological responses and thus, improving the growth performance of chickens (Atela *et al.*, 2019). Probiotic strains such as Lactobacillus are suitable for domestic animals as they inhibit the growth of pathogenic microbes while promoting the growth of beneficial microbes (Zhang *et al.*, 2021). Administering probiotics in chicken's diet improves feed utilization, thus improving feed intake, and feed conversion ratio, which could improve the overall growth performance, meat quality as well as egg production and quality (Getabalew *et al.*, 2020). Zhang *et al.* (2016) reported positive effects on body weights, average daily gains, and nutrient digestibility in Cobb 500 broiler chickens fed diets with probiotics. Similarly, Alkhalf *et al*. (2010) made positive findings on the effects of supplementing probiotics in the diet on the growth performance of broiler chicks during the starter period. Ritzi *et al*. (2016) observed that probiotic supplementation in drinking water improved body weights in broiler chicks. Zhang *et al*. (2011) reported no effect on growth performance traits throughout the growth period. Contrary to these findings, Qorbanpour *et al*. (2018) investigated the effect of probiotic supplementation and observed no effect on weight gain and feed conversion efficiency in chickens. Similarly, Atela *et al*. (2019) reported that the administration of a multi-strain probiotic to indigenous chickens did not affect average weekly feed intake and weight gain. Findings on the effects of probiotic supplementation in poultry feeds are presented in Table 1.

Table 1: Effects of including probiotics in poultry diets on growth performance.

Probiotic strain	Administration or dosage	Host	Outcomes	Authors
Commercial product (*Bacillus* ssp.)	Direct fed provided in distilled water at 5.0 x 10^6 cfu of DFM suspended in 0.5 mL	Broilers	Did not affect body weight during the starter and grower phase	Lee *et al*. (2010)
Clostridium butyricum	Supplemented in the diet at 1×10^9 cfu/kg	Arbor acres	Dietary treatment did not influence growth performance in chickens at 20 and 40 days.	Zhang *et al*. (2011)
Bacillus licheniformis.	Provided in drinking water at a dosage rate of 1.1x10^{10} cfu/ml	Broilers	Improved body weight during the grower phase while feed conversion ratio was improved throughout the experimental period.	Liu *et al*. (2012)
Pediococcus acidilactici,, *Enterococcus faecium*, *Bacillus subtilis*, *Lactococcus lactis*, and *Pediococcus pentosaceus*	Provided in drinking water at *B*.10^9 cfu/l	Japanese quail	Administration of probiotics increased body weight at 42 days.	Bazrafshan *et al*. (2012)
Multi-species *(Lactobacillus fermentum* and *Saccharomyces cerevisiae)*	Incorporated in diets at 0.2 or 1% probiotic product (containing 1 × 107 cfu/g of *Lactobacillus fermentum* JS and 2 × 10^6cfu/g of Saccharomyces cerevisiae)	Cobb broilers	Dietary treatment improved feed intake (43.5 and 43.2 g/bird/day), feed conversion ratio (1.31 and 1.33 g: g), average daily gains (33.2 and 32.6 g/bird/day), and live weights (743,2 and 731,1 g/bird) of broiler chicks during the starter phase. The dietary treatment did not affect growth performances during the grower phase.	Bai *et al*. (2013)
Lactobacillus retuteri	Direct fed probiotics mixed with standard diet at 0.1%	Male Ross 308 broilers	Improved feed conversion ratios (0.74 g: g) and body weights (202 g per bird) during the starter phase and body weight (892 g per bird) during the grower phase. However, feed intake was not affected throughout the experimental period.	Salim *et al*. (2013)
Mixture of *Lactobacillus retuteri*, *Bacillus subtilis*, and *Saccharomyces cerevisiae*	Direct fed probiotics mixed with standard diet at 0.1%	Male Ross 308 broilers	Improved body weights during the starter (205 g per bird) and grower (895 g per bird) periods, however, the dietary treatment did not affect overall feed intake and feed conversion ratios.	Salim *et al*. (2013)
Lactobacillus strains (Lactobacillus johnsonii, Lactobacillus)	Provided in standard diet	Cobb broilers	Did not improve growth performance of chickens raised in cages.	Olnood *et al*. (2015)
Pediococcus acidilactici	Supplemented in basal diet at 0.8, 1 or 1.6 g/kg of feed	Broilers	Improved body weights and daily weight gains during grower phase. Similarly, feed conversion ratio was improved with no mortalities throughout the experimental period.	Alkhalf *et al*. (2016)
Commercial probiotics (PoultryStar®)	Probiotics provided in drinking water at 20 mg/bird per day	Male Cobb 500 broilers	Improved body weights during the starter phase. However, feed intake and feed conversion ratios were not influenced by probiotic supplementation.	Ritzi *et al*. (2016)
Clostridium butyricum	Supplemented in the diet at 2 × 10^7 cfu/kg of feed	Male Cobb broilers	Did not affect body weight and average daily gain during the starter period.	Zhang *et al*. (2016)

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Probiotic strain	Administration or dosage	Host	Outcomes	Authors
Bacillus subtilis	Provided in the diet at 200 or 400 mg/kg containing 4×109 33 cfu/g of probiotics	Ross 308 broilers	Feed intake, feed conversion ratios, and weekly body weights of broiler chickens were not affected by the dietary treatment.	Fathi *et al.* (2017)
Vitafor (*Bacillus subtilis*)	Administered in drinking water at 0.5 ml (10^7 cfu/g) per kg of live weight.	Goslings	Significantly improved daily weight average gains (47.5g) and live weights (3085.4g).	Khazi-akhmetov *et al.* (2018)
Vitafor (*Bacillus subtilis*)	Administered in drinking water at 0.5 ml (10^7 cfu/g) per kg of live weight.	Broad breasted white turkey	Improved live weights (2659.5g) as well as daily weight gain (6.2g) of the birds compared to the control at 42 days.	Khazi-akhmetov *et al.* (2018)
Lactobifadol (*L. acidophilu* and *Bifidobacterium adolescentis*)	Provided in the diet at a dose of 0.2 g probiotics/g per kg of live weight	Broad breasted white turkey	Improved live weights (2743.5g) and growth rate (63.9g) at 42 days.	Khazi-akhmetov *et al.* (2018)
Lactobacillus (Commercial strains)	Probiotics provided in the diet at 1 g/kg of feed	Cobb 500	Did not affect the production performance of broilers throughout the production period.	Al-Khalaifa *et al.* (2019)
Bacillus tequilensis	Supplemented in the diet at at 200 g/ton DM.	Ross 308	Significantly improved feed conversion ratios (1.7 g: g) and improved body weight gains (2675.4g) of broiler chickens.	Hosseini *et al.* (2019)
Bacillus tequilensis	Supplemented in the diet at at 200 g/ton DM.	Ross 308 broilers	Dietary treatment did not affect feed intake throughout the production period.	Hosseini *et al.* (2019)
Combination of *Bacillus subtilis* and *Bacillus licheniformis*	Probiotics provided in the diet at 250g /100kg of feed	Broilers	Improved growth performance with respect to feed conversion ratios, daily weight gains, and live weights during the grower phase.	Roy and Khatun (2020)

Carcass quality and sensory attributes of meat from chickens fed dietary probiotics

Meat quality is an important aspect, which drives consumer purchasing decisions and consumption (Al-Shawi *et al.*, 2020). Meat quality includes meat color, tenderness or texture, and water-holding capacity (Khan *et al.*, 2018). These characteristics are influenced throughout the stages of life of an animal (Al-Shawi *et al.*, 2020). There is widespread agreement among researchers that probiotic supplementation could improve the meat quality of broilers (Zhang *et al.*, 2021; Mohammed *et al.*, 2021). Hidayat *et al.* (2016) and Khan *et al.* (2018) indicated dietary supplementation of bacteria-based substances improves meat quality and sensory properties in both male and female birds. Tenderness, which is an important attribute of meat quality, is positively affected by probiotic supplementation (Krysiak *et al.*, 2021). Studies have shown that probiotics have a positive effect on the quality aspects of both fresh and processed meat products (Trabelsi *et al.*, 2019; Bis-Souza *et al.*, 2020). Such effects include improvement in product quality and safety, extending shelf life (Kumar *et al.*, 2017), imparting unique sensory qualities (Rouhi *et al.*, 2018), and providing health benefits (Kumar *et al.*, 2017). Park *et al.* (2016) observed improved meat tenderness and shear force in broiler chickens fed a *Clostridium butyricum* based probiotic. Current reports on the effects of probiotics on the sensory attributes of poultry meat are contradicting. For instance, some studies reported a positive influence of probiotics on poultry meat sensory properties while other studies reported no influence. Studies reported a positive effect of probiotics such as *Bacillus licheniformis* and *Bacillus subtilis* on the flavor of broiler meat (Liu *et al.*, 2012; Mohammed *et al.*, 2021). Some studies reported that the chemical properties of meat are among the factors positively affected by probiotics supplementation. According to Jadhav *et al.* (2015) and Aziz *et al.* (2020), supplementation of probiotics in poultry diets results in increased muscle and organ composition and an overall increase in carcass weight depending on the composition and inclusion levels of the probiotic given. It was reported that the protein composition of thigh and breast meat increased following probiotic supplementation. Duskaev *et al.* (2020) reported that probiotics increase amounts of chemical elements in the liver depending on the composition and concentration of the probiotic administered. Ali and Abdelaziz (2018) incorporated 0.160 g and 0.175 probiotic/liter of drinking water and observed increased water absorption in pectoral and femoral muscles, while concentrations of 0.175 g probiotic/liter of drinking water gave opposite results. The decrease in shear force was positively correlated with increased muscular fat content (Yang *et al.*, 2010). In addition, the application of probiotics in broiler diets modulates the fatty acid composition of the meat through increased omega-3 fatty acids concentration such as eicosapentaenoic acid and docosahexaenoic acid. Improved protein efficiency ratio may may improve carcass yield at

Table 2: Effects of supplementing probiotics on poultry meat quality and sensory attributes.

Probiotic strain	Application or dosage	Host	Outcomes	Author
Bacillus tequilensis	Provided in the diet at 200 g/ton of feed.	Ross 308 broiler chickens	Increased carcass yield (67.4%), breast-meat (23.4%), thigh (16.8%), and spleen weight (0.2%) compared to the control group. However, probiotic supplementation did not affect the relative weight of the liver, gizzard, and heart of the birds. The abdominal fat was negatively affected (1.3%).	Hosseini *et al.* (2019)
Combination of *Bacillus subtilis* a *Bacillus licheniformis*	Probiotics provided in the diet at 250 g/100 kg of feed.	Cobb 500 Broiler chickens	Did not affect dressing percentage, thigh, and wing weights. However, improved meat quality with respect to breast meat and drumstick meat. Abdominal fat deposition was reduced.	Roy and Khatun (2020)
Bacillus subtilis	Probiotic provided in the diet at 0.25 g/kg of feed.	Ross 708 broiler chickens	Affected meat Ph and colour. Meat pH in the leg-muscle was reduced by the dietary treatment.	Mohammed *et al.* (2021)
Bacillus subtilis	Probiotic provided in the diet at 0.25 g/kg of feed.	Ross 708 broiler chickens	Increased meat colour in terms of the lightness, redness, and yellowness of leg meat.	Mohammed *et al.* (2021)
Bacillus subtilis	Probiotic provided in the diet at 0.5 or 0.25 g/kg of feed.	Ross 708 broiler chickens	Improved meat tenderness, flavor, juiciness, and texture. Supplementing probiotics increased the water holding capacity of leg meat, regardless of the supplementation levels compared to the control group.	Mohammed *et al.* (2021)
Bacillus tequilensis	Provided in the diet at 200 g/ton of feed.	Ross 308 broiler chickens	Improved carcass yields (67.4%), breast-meat (23.4%), thigh (16.8%), and spleen weights (0.2%) compared to the control group. However, probiotic supplementation did not affect the relative weights of the liver, gizzard, and heart of the birds. Abdominal fat was negatively affected (1.3%).	Hosseini *et al.* (2019)

slaughter age (Hossain *et al.*, 2012). The carcass quality of broiler chicken meat is improved by probiotics dietary inclusion (Hosseini *et al.*, 2019). Findings on the effects of probiotic supplementation on poultry meat quality and sensory attributes are presented in Table 2.

Limitations of using probiotics in poultry production

Though probiotics are regarded as an alternative growth promoter with many benefits in terms of health and growth performance. The efficacy of probiotics in improving the host's performance and product quality hinges on factors such as probiotic strain being used as well as stability during storage, supplementation method, frequency and dosage, breed, sex, age, and health status of the host animal (Al-Shawi *et al.*, 2020). Furthermore, probiotic products are fragile, and inadequate handling or conservation after acquisition may inactivate them (Bahule and Silva, 2021). Some literatures have demonstrated that the use of probiotics may pose a threat to the host animal's defense mechanisms (Milner *et al.*, 2021). It has been documented that an overdose of probiotics can lead to the deterioration of semen and possibly lead to infertility in breeders (Krysiak *et al.*, 2021). Therefore, proper dosages are recommended when using probiotics in roosters.

CONCLUSIONS AND RECOMMENDATIONS

Recently, there has been an increase in the demand for the production of organic foods and drug residue-free animals by international health organizations in order to meet human health standards. Based on this review, it can be concluded that probiotics and prebiotics were developed in order to reduce inappropriate application and mismanagement of antibiotics in poultry production, which have negative health effects on human health. Therefore, the present study reviewed the application of probiotics in place of antibiotics as growth promoters in chickens. Evidence from peer-reviewed and published manuscripts have shown that activities from livestock production are the major drivers of drug resistance. Following restrictions on antibiotic use, the use of probiotics has become popular. Overall search results have indicated that probiotics could be safely used in commercial poultry feeds to improve chicken productivity, improve meat quality, as well as meat acceptability. However, the choice of probiotic strain to be utilized, and application method or dosage will depend on the bird parameters or meat attributes that are being targeted. More studies are recommended to ascertain the findings reported in this review.

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NOVELTY STATEMENT

The study explored the response in performance and meat attributes after probiotic supplementation in poultry.

Ethics approval

This study requires no ethics.

Conflict of interest

The authors have declared no conflict of interest.

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