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Organic acids supplementation in poultry nutrition: A review

Vasko Gerzilov[1], Pavlina Hristakieva[2*]

[1]*Department of Animal Science, Faculty of Agronomy, Agricultural University, Plovdiv, Bulgaria*
[2]*Agricultural Academy, Agricultural Institute, Stara Zagora, Bulgaria*

ABSTRACT
The poultry industry is continually exploring new feed additives to enhance poultry productivity and health. Since the European Union's (EU) 2006 ban on antibiotics as growth promoters, alternative methods have become essential to support health and growth in livestock production. In response, various strategies have been developed to replace nutritional antibiotics, aiming to combat antibiotic resistance and manage diseases that would otherwise require antibiotic intervention. One promising alternative is the incorporation of organic acids (OAs) and their salts as feed additives in poultry farming. OAs improve feed palatability, reduce pH levels in the gastrointestinal tract of birds, activate digestive enzymes, and inhibit the growth of pathogenic microorganisms while preserving beneficial microflora. These acids enhance metabolism, improve feed digestibility, and accelerate growth. Additionally, OAs support overall bird health, a key factor affecting productivity traits and, consequently, the economic performance and profitability of poultry farming. This article examines the potential applications of OAs in poultry nutrition.
Keywords: Antibiotic alternatives, Growth performance, Egg production, Organic acids.

Introduction

In 2006, the European Commission (EC) banned antibiotics as growth promoters in animal feed under EU Regulation No. 1831/2003, leading to declines in productivity and increased rates of certain animal diseases. This policy shift has driven researchers to investigate alternative non-therapeutic additives—such as organic acids (OAs), enzymes, probiotics, prebiotics, herbs, essential oils, and immunostimulants—to support health and productivity in poultry (Suresh *et al.*, 2018; Lalev *et al.*, 2020; Lalev *et al.*, 2022a,b; Mincheva *et al.*, 2022; Ivanova *et al.*, 2022; Hristakieva *et al.*, 2023; Akan *et al.*, 2025). Among these, OAs are gaining attention as effective replacements, traditionally used as preservatives to extend shelf life in perishable foods (Coban, 2020; Braïek and Smaoui, 2021).

OAs are weak acids containing a carboxylic acid group (R-COOH) and are intermediates in metabolizing carbohydrates, amino acids, and lipids. Commonly employed as antimicrobial additives in animal feed, these compounds include saturated straight-chain monocarboxylic acids and their derivatives (e.g., unsaturated, hydroxyl, phenolic, and multicarboxylic acids) and are often referred to as fatty acids, volatile fatty acids, or carboxylic acids (Cherrington *et al.*, 1991). OAs are known for their antimicrobial efficacy against pathogenic bacteria, lowering GIT pH, thereby enhancing nutrient absorption and feed efficiency (Boling *et al.*, 2000; Lesson *et al.*, 2005; Kim *et al.*, 2015). Their effectiveness as antimicrobials is primarily determined by their pKa values, which typically range between 3 and 5 (Freitag, 2007; Huyghebaert *et al.*, 2011). Table 1 summarizes the properties of selected OAs and salts commonly used in poultry farming.

OAs function as antimicrobials based on various physicochemical properties, including molecular weight, pKa, and minimum inhibitory concentration, along with factors such as the nature of the target microorganism and the buffering capacity of the feed (Dittoe *et al.*, 2018; Coban, 2020). An acid's pKa indicates its dissociation capacity, denoting the pH at which the acid exists equally in dissociated and undissociated forms. In the undissociated state, OAs can penetrate bacterial and fungal cell walls, altering microbial metabolism. Thus, their antimicrobial efficacy is enhanced in acidic environments like the stomach and reduced at neutral pH levels, as in the intestine. OAs with higher pKa values are typically weaker acids and more effective feed preservatives because they remain largely undissociated, effectively protecting feed from microbial spoilage. Conversely, acids with lower pKa values more readily dissociate, lowering gastric pH but having a limited antimicrobial impact in the intestine (Theobald, 2018).

***Corresponding Author:** Pavlina Hristakieva. Agricultural Academy, Agricultural Institute, Stara Zagora, Bulgaria.
Email: *poly_31@abv.bg*

Table 1. Properties of some acids and salts used in poultry.

Organic acid/salt	pK value	Solubility in water	Molecular weight (g)	Energy (KJ/g)	Physical state
Formic acid	3.37	Very good	48.0	5.8	Liquid
Acetic acid	4.75	Very good	60.1	14.8	Liquid
Propionic acid	4.78	Very good	74.1	20.8	Liquid
Lactic acid	3.08	Good	90.1	15.1	Liquid
Fumaric acid	3.03/4.44	Low	116.1	11.5	Solid
Citric acid	3.14/5.95	Very good	210.1	10.3	Solid
Ca-formate	–	Low	130.1	3.9	Solid
Na-formate	–	Very good	68.0	3.9	Solid
Ca-propionate	–	Good	16.6	16.6	Solid
Ca-lactate	–	Low	10.2	10.2	Solid

Freitag (2007) by Kirchgessner and Roth (1988).

This review discusses the structure, properties, mechanisms of action, biological functions, and applications of OAs in poultry nutrition.

How do the OAs work?

The general chemical formula of the organic acid is R-COOH (undissociated form). In this form, they can release a proton (H+), which lowers the pH of the gut. The reduction in pH inhibits the proliferation of pathogenic bacteria, such as *Escherichia coli*, *Salmonella spp.*, and *Campylobacter spp.*, while simultaneously promoting the growth of beneficial bacteria, such as lactic acid bacteria.

This pH effect is not the only effect that individual acids have, but OAs also have antibacterial activity (Theobald, 2018). The antibacterial activity of OAs increases with decreasing pH and is characterized by the reduction of pH, as well as their ability to dissociate, which is determined by the pKa value of the corresponding acid and the pH of the environment. OAs are lipid soluble in the undissociated form and can enter the microbial cell (Partanen and Mroz, 1999). In undissociated form, acidic molecules can easily penetrate the microbial cell walls of gram-negative bacteria. Inside the cell, the pH is higher than the pKa, and much of the acid dissociates and releases its hydrogen ion (H+). Upon release of hydrogen ions (H+), the microbial cell expends enormous amounts of energy that lead to cell death (Dibner and Buttin, 2002; Gümrükçüoğlu, 2022).

Once inside the cell, the acid releases the proton into the more alkaline environment, causing the pH in the cell to decrease. This affects microbial metabolism by inhibiting the action of important microbial enzymes and forcing the bacterial cell to use energy to release protons, leading to an intracellular accumulation of acidic anions. This accumulation depends on the difference in pH. Generally, the antimicrobial effect of OAs increases with increasing concentrations (Lucera *et al.*, 2012; Braïek and Smaoui, 2021)

OAs exert their antimicrobial effect through the water that enters the animal's gastrointestinal tract (GIT). The pH in the digestive tract will decrease if the ingested water becomes acidified. This has a positive effect on digestion, especially in the stomach and small intestine (small bowel).

The extent of pH reduction in feed and within the GIT following the addition of OAs is influenced by both the pKa values of the specific OAs and the existing pH conditions in the GIT (Kim *et al.*, 2005). Incorporating OAs into broiler feed results in a pH decrease across various segments of the GIT. Generally, the pH reduction is more pronounced in the upper GIT sections (crop, proventriculus, and gizzard) compared to the lower GIT regions (duodenum, jejunum, ileum, and cecum) (Thompson and Hinton, 1997).

OAs are absorbed across the intestinal epithelium by passive diffusion and contribute a significant amount of energy (Table 1). OAs are absorbed across the intestinal epithelium by passive diffusion, and most OAs contribute a significant amount of energy (Table 1). They, therefore, represent an alternative energy source that can be efficiently utilized by cells through their incorporation into the Krebs cycle. For example, fumaric acid, which is a four-carbon dicarboxylic acid and an intermediate metabolite in the Krebs cycle, can contribute to cellular energy supply by participating in mitochondrial metabolism, generating a moderate amount of ATP upon complete oxidation (Ryan *et al.*, 2022). With an energy content of approximately 1340 kJ/mol, this corresponds to about 74.3 kJ for the synthesis of 1 mole of ATP, a value comparable to the energy efficiency observed during glucose degradation (Nelson and Cox, 2021). This makes fumaric acid comparable to glucose as an energy substrate. Similar values are also observed for citric acid. In contrast, acetic and propionic acids require approximately 18% and 15% more energy, respectively, to synthesize 1 mole of ATP, making them relatively less efficient in terms of energy yield (Lobley, 2001; Gaudieri *et al.*, 2020).

Acidifiers are utilized in poultry farming through three primary methods:

Feed additives

Acidifiers are incorporated into poultry feed in either solid or liquid form, inhibiting bacterial growth within the feed while simultaneously lowering the pH in the birds' GIT.

Litter treatment

Acidifiers are applied to poultry litter, targeting bacteria involved in uric acid breakdown. This process reduces ammonia release, contributing to a healthier rearing environment.

Water additives

Acidifiers are introduced into drinking water to reduce the GIT pH and eliminate pathogenic bacteria, thereby promoting digestive health and supporting the bird's immune defense against harmful microbes.

Some OAs used in poultry farming

Propionic acid

Propionic acid ($C_3H_6O_2$) is a clear liquid with a sharp, unpleasant odor, produced through the anaerobic degradation of pyruvic acid in the cytosol. Pyruvic acid, in turn, is derived from glycolysis, where one glucose molecule is converted into two molecules of pyruvic acid. Propionic acid is commonly used as a preservative in animal feed and human food, as a growth promoter, and as a feed additive, especially for poultry and pigs, either in its direct form or as an ammonium salt. It exhibits high activity against mold and yeast but is comparatively less effective against bacteria (Zha and Cohen, 2014).

Acetic acid

Acetic acid (CH_3COOH) is a weak acid that, despite its limited dissociation in aqueous solutions, is corrosive, and its fumes can irritate the eyes and nasal passages. In household use, its 6% and 9% solutions are known as vinegar. Acetic acid is effective against yeast and bacteria but has a limited effect on molds. Abbas et al. (2011) observed an anticoccidial effect of acetic acid, added at 0.5% concentration to drinking water, against Eimeria tenella in broiler chickens.

Benzoic acid

Benzoic acid (C_6H_5COOH) is an aromatic carboxylic acid with slight water solubility, known for its antiseptic properties. It is effective against yeast and bacteria, including putrefactive bacteria, but has a lesser effect on molds. It plays a key role in reducing the prevalence of various pathogenic bacteria, including Campylobacter jejuni, Escherichia coli, Listeria monocytogenes, and Salmonella enterica (Friedman et al., 2003).

Sorbic acid

Sorbic acid ($CH_3(CH)_4CO_2H$) is a colorless solid with limited water solubility that sublimes readily. Sorbic acid and its salts—sodium sorbate, potassium sorbate, and calcium sorbate—are commonly used as antimicrobial agents in foods and beverages to prevent mold, yeast, and fungal growth. The salts are preferred over the acid form due to their greater water solubility, though the acid form is most active against microorganisms (Lück, 1990). Sorbic acid demonstrates a broad spectrum of action, being particularly effective against yeast, mold, and bacteria, surpassing the antimicrobial efficacy of propionic acid (Razavi-Rohani and Griffiths, 1999)

Formic acid

Formic acid (CH_2O_2), the simplest carboxylic acid, is highly soluble in water and many polar organic solvents, with limited solubility in hydrocarbons. It exhibits effectiveness against yeast and bacteria but is less active against mold. While beneficial against pathogenic bacteria, formic acid may cause mucosal irritation upon inhalation in its liquid form and can irritate the skin on contact. Formates, the solid salt forms, are less corrosive. Given potential health risks, handling formic acid requires adherence to safety regulations (Dibner and Buttin, 2002; Huyghebaert et al. 2011).

Citric acid

Citric acid ($C_6H_8O_7$), a weak organic acid, functions as a natural preservative and feed additive for poultry and swine. It plays a role in carbohydrate metabolism, and although birds can synthesize vitamin C (ascorbic acid), supplemental citric acid can be beneficial, particularly under conditions that may impair endogenous vitamin C synthesis, such as stress (Islam et al., 2008, 2010, 2012). Citric acid also exhibits antimicrobial properties, helping to preserve feed and reduce bacterial pathogens (e.g., E. coli) in the GIT, ultimately promoting growth (Eidelsburger and Kirchgessner, 1994; Deepa et al., 2011).

Fumaric and succinic acids

Fumaric ($CHCO_2H$) and succinic acids ($C_4H_6O_4$) are used in poultry nutrition to enhance resistance, reduce post-stress impacts, and mitigate gastrointestinal and respiratory diseases. They also serve as supplemental energy sources, enhancing appetite and supporting growth in young animals (Ding et al., 2020; He et al., 2020; Waghmare et al., 2025).

Influence of dietary OAs on poultry performance

Many OAs, enzymes, phytogenic compounds, probiotics, prebiotics, and other biologically active compounds are routinely incorporated into poultry feed or drinking water to promote growth, enhance feed digestibility, and improve bird health (Gerzilov *et al.*, 2019; Lalev *et al.*, 2020, 2022b, 2023; Petrov *et al.*, 2022; Hristakieva *et al.*, 2021, 2023). OAs serve as acidifiers in poultry feed and are increasingly considered viable antibiotic alternatives for enhancing nutrient digestibility and promoting productivity (Fascina *et al.*, 2012). They support gastric proteolysis and improve protein and amino acid digestibility (Samanta *et al.*, 2010). Their impact on broilers and laying hens is described in the following.

Broiler chickens

Numerous studies have demonstrated that various OAs such as fumaric (Hernández *et al.*, 2006; Ghazala *et al.*, 2011), formic (Hernández *et al.*, 2006; García *et* *al.*, 2007), acetic (Hernández *et al.*, 2006), citric (Ao *et al.*, 2009), and ascorbic (Lohakare *et al.*, 2005) acids enhance the digestibility of crude protein (CP), crude fiber (CF), and nitrogen-free extracts (NFE) in broilers. Dietary inclusion of OAs has been shown to promote growth, feed efficiency, nutrient utilization, and pathogen inhibition (Lückstädt and Mellor, 2011; Brzoska *et al.*, 2013; Mustafa *et al.*, 2021; Dittoe *et al.*, 2018). For example, Fascina *et al.* (2012) found that OA mixtures in broiler feed increased productivity and slaughter performance, observing increased carcass yield and higher breast meat content in diets with OAs and phytoadditives. Adil *et al.* (2011) noted optimal live weights in broilers fed with 3% fumaric acid supplementation. Brzoska *et al.* (2013) reported growth enhancements and decreased mortality in broilers given OAs at concentrations of 0.3%–0.9%, though no significant effect was found on carcass yield. Hashemi *et al.* (2014) documented body weight gains when a blend of OAs (including formic, phosphoric, lactic, tartaric, citric, and malic acids) was administered at 0.15%. OAs supplementation has also been linked to improved meat quality, potentially mitigating pale, soft, and exudative (PSE) conditions in broiler meat (Sugiharto *et al.*, 2019). Studies have shown that citric acid supplementation is associated with increased weight gain (Afsharmanesh *et al.*, 2005; Nezhad *et al.*, 2007) and improved feed intake (Chowdhury *et al.*, 2009; Haque *et al.*, 2010; Nourmohammadi *et al.*, 2010; Salgado-Tránsito *et al.*, 2011). This resulted in a lower FCR in diets containing citric acid compared to controls. This improvement in efficiency was associated with better nutrient absorption, a decrease in intestinal pH, and inhibition of pathogenic microflora in the digestive tract. Effects on organ development were noted by Skvortsova and Gorkovenko (2017), with citric acid supplementation, promoting heart, intestinal, gizzard, and liver development in broilers. Additionally, Skvortsova (2018) found that the differentiated inclusion of citric acid in broiler diets—where the additive concentrations are adjusted according to the age or growth phase of the birds—led to a 3.2% reduction in feed costs, accompanied by a 2.8% increase in the carcass weight and an improvement in meat quality. This approach optimizes the effects of the additive by tailoring the dosage to the specific needs and physiological characteristics of the birds at different stages of their development, thereby enhancing the efficiency and economic viability of the feeding program. Contrastingly, Kopecký *et al.* (2012) found no significant body weight or carcass impact from diets containing acetic and citric acids (0.25% in water); however, a reduction in total mortality was observed.

Laying hens

The addition of OAs such as propionic, fumaric, sorbic, and lactic acids, along with their salts, influences both egg-laying performance and egg quality (Gama *et al.*, 2000; Yalcin *et al.*, 2009). Research by Yesilbag and Çolpan (2006) demonstrated that OAs supplementation in the diets of Lohmann laying hens aged 24–28 weeks significantly enhanced laying performance compared to control groups, extending the overall laying period. These findings align with other studies, concluding that supplementation of OAs positively affects egg production metrics, including shell strength, yolk and albumen indices, and shell thickness (Boling *et al.*, 2000; Gama *et al.*, 2000).

In a study by Soltan (2008), laying hens fed a basal diet supplemented with 780 ppm OAs (ProviMax®) showed a 5.77% increase in egg production compared to the control group. Lower supplementation levels (260 and 520 ppm) did not yield statistically significant changes, a result corroborated by Rahman *et al.* (2008). Similarly, Kadim *et al.* (2008) evaluated the impact of acetic acid supplementation (200, 400, and 600 ppm) on Brown Leghorn hens, observing increases in productivity of approximately 10%, 15%, and 20%, respectively, across treatment groups relative to controls.

Grashorn *et al.* (2013) assessed the effects of OAs supplementation (SALMO-NIL DRY® at 2 kg/ton) in the diets of 30-week-old Hisex Brown hens. Findings indicated significantly improved laying intensity and feed conversion ($p < 0.05$) in the OAs-supplemented group. Conversely, Kaya *et al.* (2015) reported that an OA mixture (60% formic acid, 20% propionic acid) did not impact feed intake, laying performance, egg weight, feed conversion, or body weight, though it did improve intestinal histomorphology, except for crypt depth.

Dahiya *et al.* (2016) further demonstrated that adding 1.5% sodium butyrate enhanced laying rates, while a 0.5% supplementation improved egg weight but reduced laying frequency. Youssef *et al.* (2013a) similarly found that probiotics, prebiotics, synbiotics, or OAs supplementation in laying hen diets increased egg production, egg mass, and quality. Shalaei *et al.* (2014) also reported that a mixture of formic, lactic, and orthophosphoric acids notably increased the egg weight in hens aged 32 to 42 weeks.

Antimicrobial activity of OAs in poultry

Pathogenic microbes or bacteria that proliferate in the GIT can damage the intestinal villi by inducing cell proliferation, leading to thickening of the intestinal tissue. This thickening hinders nutrient absorption, ultimately resulting in reduced growth and development in animals. OAs can penetrate the cell walls of these pathogenic microbes, disrupting normal cellular functions and causing microbial cell death. The low pH created by these acids establishes a stressful environment that contributes to cellular dysfunction and inhibits bacterial growth.

Numerous studies have reported reductions in pathogenic bacteria within the GIT of birds, leading to decreased morbidity and mortality when OAs are incorporated into their diets (Kazempour and

Jahanian, 2017; Fouladi *et al.*, 2018; Thi Thuy *et al.*, 2018). For instance, Sheikh *et al.* (2010) observed that the use of an OAs mixture significantly reduced gram-negative bacterial counts in the guts of broiler chickens. Aydin *et al.* (2010) found that adding 3% citric acid to the basal diet significantly decreased coliform content in the ileum compared to the control group ($p < 0.05$). The inclusion of citric acid creates an acidic environment (pH 3.5 to 4.0) in the small intestine (duodenum and jejunum), where normal pH ranges around 5.5–6.5. Thus, promoting the growth of beneficial lactobacilli while inhibiting the replication of *Escherichia coli*, *Salmonella*, and other gram-negative bacteria (Chowdhury *et al.*, 2009). In more distal parts of the intestine, such as the cecum, the pH is more alkaline and the effect of citric acid is less pronounced.

Research has shown that broiler chickens fed diets containing mixtures of OAs exhibit lower levels of pathogenic bacteria, such as coliforms and clostridia, while maintaining higher populations of beneficial bacteria, such as lactobacilli, in the ileum compared to those receiving antibiotic growth promoters (Khan and Iqbal, 2015). Lückstädt and Theobald (2009) previously reported that the addition of sodium diformate (a compound of formic acid and sodium formate) to feed reduced the presence of pathogenic bacteria (e.g., *Salmonella, Campylobacter*, and *Escherichia coli*) in broiler chickens while increasing populations of lactobacilli and bifidobacteria. Paul *et al.* (2007) found that the organic acid salts, ammonium formate, and calcium propionate (3 g/kg feed), also significantly reduced coliform counts in broilers compared to control groups.

Influence of OAs on blood biochemical parameters in poultry

Yesilbag and Çolpan (2006) supplemented the basal diet of laying hens with various levels (0.5%, 1.0%, and 1.5%) of an OAs mixture. Their findings indicated that supplementation with 1% and 1.5% OAs significantly increased serum total protein and albumin concentrations, while other serum parameters, including cholesterol, high-density lipoprotein (HDL), triglycerides, total lipid concentration, and alanine aminotransferase (ALT) activity, were not significantly affected. Summarized findings from Baghban-Kanani *et al.* (2019) and Kamal and Ragaa (2014) also reported a significant reduction in serum low-density lipoprotein (LDL) levels in a group of birds receiving acidifiers. The beneficial role of OAs in reducing the blood lipid profile may be attributed to their ability to lower microbial intracellular pH, thereby inhibiting the action of key microbial enzymes and forcing bacterial cells to expend energy to release acidic protons, which leads to intracellular accumulation of acidic anions (Kamal and Ragaa, 2014).

Soltan (2008) investigated the effects of varying concentrations of an OAs mixture (0, 260, 520, and 720 ppm) in hen diets, observing a linear increase in serum calcium concentration corresponding to the levels of organic acid. Moreover, serum total protein and albumin concentrations were significantly improved ($p < 0.01$) in the experimental groups compared to the control group. This enhancement is likely due to the favorable intestinal environment created by the addition of OAs, which lowers the GIT's pH, improving protein digestibility and facilitating mineral absorption. Moreover, the elevated levels of serum protein and albumin may reflect an increased availability of circulating proteins, potentially resulting from enhanced protein synthesis and nutrient absorption. Wang *et al.* (2009) reported significant increases ($p < 0.05$) in total protein and albumin levels when the diets of 36-week-old ISA Brown hens were supplemented with phenyllactic acid. In contrast, Ozek *et al.* (2011) found no significant difference in serum total cholesterol levels when diets were supplemented with a mixture of herbal essential oils and OAs in laying hens. Kaya *et al.* (2013) investigated the effects of adding a mixture of zeolite and OAs to the diet of laying hens and observed significant reductions ($p < 0.05$) in serum albumin and calcium levels, with no impact on serum cholesterol, total protein, or phosphorus levels. Youssef *et al.* (2013a, b) reported significant improvements ($p < 0.05$) in plasma calcium and phosphorus concentrations in 53-week-old laying hens supplemented with sodium formate during the summer season.

Nourmohammadi *et al.* (2011) examined the effects of citric acid and microbial phytase in broiler chickens, finding significant reductions in plasma cholesterol and phosphorus concentrations with citric acid inclusion, while plasma calcium and magnesium concentrations remained unaffected. Kamal *et al.* (2014) studied the effects of different types of OAs (butyric, fumaric, or lactic acid) supplementation at 3% inclusion on the performance and blood biochemistry of broiler chickens. The study reported reductions in total cholesterol and serum LDL levels in the birds fed organic acid supplements compared to the basal diet.

Other possible effects of* OAs *in poultry

Previous studies have indicated that OAs can enhance phosphorus utilization in corn-soy broiler diets (Boling *et al.*, 2000; Esmaeilipour *et al.*, 2011). Adil *et al.* (2010) found that blood serum concentrations of calcium and phosphorus were higher in broilers fed diets supplemented with OAs compared to those in the control group. This improvement may be attributed to the formation of acid anion complexes with minerals such as calcium and phosphorus, which enhances their absorption (Li *et al.*, 1998; Kishi *et al.*, 1999).

Some researchers have also suggested that OAs may stimulate energy metabolism by serving as energy sources for epithelial cells in the GIT (Ravindran and Kornegay, 1993; Partanen and Mroz, 1999). For instance, fumaric and citric acids act as intermediates in the tricarboxylic acid cycle, while butyric acid serves as a direct energy source for epithelial cells in the GIT (Partanen and Mroz, 1999; Pryde *et al.*, 2002) and also as an energy source for the gut microbiota.

According to Hajati (2018), there are several limitations to the use of OAs in poultry nutrition. These include feed refusal due to decreased palatability, the corrosive nature of OAs to metal equipment used in poultry feeding, the development of acid resistance in bacteria when exposed to acidic environments over prolonged periods, the potential reduction in the efficacy of OAs in the presence of other antimicrobial compounds, deterioration of cleanliness in the production environment, and the buffering capacity of feed ingredients.

Conclusion

Dietary OAs are considered promising alternatives to antibiotic growth promoters that were previously used to enhance the growth and health of poultry. Acidifying the feed lowers the pH in the GIT, which can improve nutrient utilization and inhibit pathogenic microorganisms. The effects of OAs depend on both the type of acid used and the levels of their incorporation into the diet.

A review of existing studies indicates that most OAs added to poultry diets generally improve performance and health status, although some conflicting results have been reported. Further research is necessary to elucidate the mechanisms of action, optimal dosages, and the overall impact of OAs on productivity, health, and the quality of poultry products as alternatives to antibiotic growth promoters.

The potential of OAs can be further enhanced through the application of modern science and technology, particularly at the molecular, biotechnological, and nanotechnological levels, to validate and expand their beneficial uses.

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Authors' contributions

VG and PH drafted the manuscript. PH revised and edited the manuscript.VG participated in critical checking of the final manuscript. PH edited the references. Both authors have read and approved the final manuscript**.**

Conflict of interest

The authors have no conflicts of interest to declare.

Data availability

All data are provided in the manuscript.

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