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REVIEW ARTICLE

Recent advances in the role of organic acids in poultry nutrition

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ABSTRACT
In recent years, there has been an increase in the use of organic acids as substitutes for antibiotic growth promoters because of the fear of antibiotic resistance and the implications for human health. Organic acids and their salts have been used in poultry diets and drinking water for decades and seem to elicit a positive response in growth performance. An important objective of dietary acidification is the inhibition of intestinal bacteria competing with the host for available nutrients, and a reduction of possible toxic bacterial metabolites resulting in the improvement of nutrient digestibility, thereby ameliorating the performance of birds and enhancing the specific and non-specific immunity in poultry. Literature shows that short-chain fatty acids, medium-chain fatty acids and other organic acids have more or less pronounced antimicrobial activity, depending on both the concentration of the acid and the bacterial species that is exposed to the acid. The possible mechanisms contributing to these effects and the factors thought to explain the variability in these responses are discussed. This paper provides a review of the use of organic acids in the prevention of enteric disease in poultry, the effect on the gastrointestinal tract, nutrient digestibility, immunity and performance of broiler and laying hens.

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1. Introduction

High levels of production and efficient feed conversion are the need of the modern poultry industry, which to a certain extent could be achieved by the use of specific feed additives. Antibiotic feed additives as growth promoters have long been supplemented to poultry feed to stabilize the intestinal microbial flora, improve the general performances and prevent some specific intestinal pathology (Hassan et al. 2010). However, due to the emergence of microbes resistant to antibiotics which are used to treat human and animal infections, the European Commission (EC) decided to phase out, and ultimately ban (1 January 2006), the marketing and use of antibiotics as growth promoters in feed (EC Regulation No. 1831/2003; http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:268:0029:0043:EN:PDF). In other countries, such as the USA, consumer pressure is pushing the poultry industry to rear birds without antibiotics (Castanon 2007). Antibiotics removal has led to poultry performance problems, feed conversion increases and a rise in the incidence of certain animal diseases, such as (subclinical) necrotic enteritis (Dibner & Richards 2005). Such a situation has compelled the researchers to explore the utility of other non-therapeutic alternatives like organic acids, enzymes, probiotics, prebiotics, herbs, essential oils and immunostimulants as feed additives in poultry production.

Organic acid treatments composed of individual acids and blends of several acids have been found to perform antimicrobial activities similar to those of antibiotics (Wang et al. 2009). The European Union allowed the use of organic acids and their salts in poultry production because these are generally considered safe (Adil et al. 2010). Organic acids have been used for decades in commercial compound feeds, mostly for feed preservation, for which formic and propionic acids are particularly effective (Lückstädt 2014). In the European Union, these two organic acids and several others (lactic, citric, fumaric and sorbic acids) and their salts (e.g. calcium formate, calcium propionate) are used under the classification 'feed preservative' (Lückstädt & Mellor 2011). As a group of chemicals, organic acids are considered to be any organic carboxylic acid of the general structure R-COOH (including fatty acids and amino acids). The short-chain acids (C1–C7) are associated with antimicrobial activity. They are either simple mono-carboxylic acids such as formic, acetic, propionic and butyric acids or carboxylic acids with the hydroxyl group such as lactic, malic, tartaric and citric acids or short-chain carboxylic acids containing double bonds like fumaric and sorbic acids (Shahidi et al. 2014).

Organic acids are weak acids and are only partly dissociated. Most organic acids with antimicrobial activity have a pKa (the pH at which the acid is half dissociated) between 3 and 5. A wide range of organic acids with variable physical and chemical properties exists, of which many are used as drinking water supplements or as feed additives (acidifiers). Many are also available as sodium, potassium or calcium salts (and/or partially esterified). The advantage of salts over acids is that they are generally odourless and easier to handle in the feed-manufacturing process owing to their solid and less volatile form. They are also less corrosive and may be more soluble in water (Huyghebaert et al. 2011). The use of organic acids has been reported to protect the young chicks by competitive exclusion (Mansoub et al. 2011), enhancement of nutrient utilization, and growth and feed conversion efficiency (Lückstädt

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& Mellor 2011). This publication presents recent studies on the effect of organic acids on enteric diseases, gastrointestinal tract, nutrient digestibility, immunity and performance in broiler and laying hens.

2. Antimicrobial activity of organic acids

The addition of organic acids in diet can have a beneficial effect on the performance of poultry by decreasing pathogenic bacteria. Most common bacteria that affect the intestinal health of poultry are *Salmonella, Campylobacter* and *Escherichia coli* which can be controlled by supplementation of an organic acid in diet (VanImmerseel et al. 2006; Naseri et al. 2012). *Salmonella* is a human pathogen that is commonly found in poultry products. From a public health point of view, it is necessary to control this biological hazard. It is possible to decrease chicken carcass and egg contaminations by adding organic acids to the feed or drinking water at appropriate times, which can hinder its multiplication (Russell & Diez Gonzalez 1998). *Salmonella* infection in poultry is mainly spread by contaminated feed (Koyuncu et al. 2013). The presence of *Salmonella* in poultry feed as well as feed ingredients such as grain, oilseed meal, feathers, fishmeal, blood meal, meat by-products and broiler feed has been documented (Meeker 2009; Cressey et al. 2011; Petkar et al. 2011; Hald et al. 2012; Andino 2014). *Salmonella* can multiply in the gastrointestinal tract of birds and potentially be excreted in the faeces during growing phase (Kušar et al. 2010). Koyuncu et al. (2013) investigated the efficacy of each 1.0% of formic acid and different blends of formic acid, propionic acid and sodium formate in different feed materials. No difference in *Salmonella* reduction was observed between formic acid and a blend of organic acids. The *Salmonella Infantis* strain was found to be the most acid-tolerant strain followed by *Salmonella Putten, Salmonella Senftenberg* and *Salmonella Typhimurium* (Koyuncu et al. 2013). The strongest reduction was seen in pelleted and compound mash feed (2.5 $\log_{10}$ reduction) followed by rapeseed meal (1 $\log_{10}$ reduction) after 5 days of exposure of 1% formic acid. However, in a soybean meal the acid effects were limited (less than 0.5 $\log_{10}$ reduction) even after several weeks' exposure (Koyuncu et al. 2013). Izat et al. (1990) reported that the buffered propoinic acid at 4% fed continuously or during the last 7 days of the trial produced a significant reduction in the number of *Salmonella* on post chill carcasses when the broilers were periodically dosed with *Salmonella*. There was no significant effect from propoinic acid on the number of *Salmonella* or of *coliforms* in the small intestine, but there was a significant reduction in the total number of *Salmonella* and of *coliforms* when 4% propionic acid was fed either continuously or during the last 7 days of the trial.

Currently, drinking water acidification is another implementation in the broiler industry used for improving performance. Subsequent studies indicated that addition of organic acid to the drinking water helps to reduce the level of pathogens in the water and the crop/proventriculus, to regulate gut microflora, to increase the digestion of feed and to improve growth performance (Byrd et al. 2001; Açıkgöz et al. 2011; Hamed & Hassan 2013). Byrd et al. (2001) suggested that incorporation of 0.5% organic acids (lactic acid, acetic acid or formic acid) in the drinking water during pre-transport feed withdrawal may reduce *Salmonella* and *Campylobacter* contamination of crops and broiler carcasses at processing. They suggested that the lactic acid provided in the drinking water reduces the pH of the crop and might be provided as a temporary carbon source for beneficial bacteria normally present in the crop. Açıkgöz et al. (2011) reported that the total organism counts for control and acidified water (formic acid was added to the control water until the pH was adjusted to 3) groups were 6.17 and 5.84 log cfu/g, respectively. The intestinal *E. coli* population was found to be 4.15 and 4.02 log cfu/g in birds given control and acidified water, respectively. Moreover, the use of formic acid in the drinking water did not significantly affect the number of *Salmonella*-positive intestines.

Similarly, organic acid mixtures (fumaric acid, calcium format, calcium propionate, potassium sorbate, calcium butyrate, calcium lactate and hydrogenated vegetable oil) were found to be more efficient than the antibiotic growth promoter (Enramycin) in decreasing intestinal *E. coli* and *Salmonella* spp. (Hassan et al. 2010). Hamed and Hassan (2013) reported that a significant ($P < .5$) reduction in total bacterial count in ceca was observed in both the groups treated with acetic acid (3 mL/L) and organic acid mixture (3 mL/L; acetic acid, phosphoric acid, lactic acid, fumaric acid and tartaric acid), which were administered through drinking water to Japanese quails at 7 days post infection as compared to the non-treated group. These studies explained that the key basic principle of the mode of action of organic acids on bacteria is that non-dissociated organic acids can penetrate the bacteria cell wall and disrupt the normal physiology of certain types of bacteria that we call 'pH sensitive' meaning that they cannot tolerate a wide internal and external pH gradient. Furthermore, the organic acids in poultry might have a direct effect on the gastrointestinal tract (GIT) bacteria population, reducing the level of some pathogenic bacteria and mainly controlling the population of certain types of bacteria that compete with the birds for nutrients.

Paul et al. (2007) found that organic acid salt (ammonium formate or calcium propionate; 3 gm/kg diet) reduced *coliform* count in broiler feed compared to control, whereas the *clostridium* count was unaffected. The results also showed that ammonium formate supplementation also lowered *E. coli* count in the gut but the *clostridium* count was unaffected. However, calcium propionate could reduce fungal count better compared with ammonium formate in the feed. This may be due to the fact that the propionic acid or propionate possesses mainly anti-mould characteristics (Zha and Cohen 2014). Mikkelsen et al. (2009) showed that 0.45% potassium diformate reduced mortality caused by necrotic enteritis (*Clostridium perfringens*). After the necrotic enteritis outbreak (day 35 of the trial period), potassium diformate significantly reduced the number of *C. perfringens* in the jejunum. Fernández-Rubio et al. (2009) found that sodium butyrate (in both partially protected with vegetable fats and unprotected forms) was able to prevent *Salmonella* colonization in the crop and caeca of broilers, whereas only the partially protected source of the butyrate salt reduced internal organ colonization (liver). Partially protected sodium butyrate tended to have better results than the non-protected presentation of the additive in faecal *Salmonella* excretion. The vegetable fats protecting sodium butyrate in the partially protected butyrate additive provided better resistance to the acidic pH and allowed part of the butyrate to be released further down the intestine. The vegetable fat protection allows sodium butyrate to have an effect all along the GIT tract because it is slowly released during digestion. It has, therefore, a positive effect on bird health by preventing *Salmonella* colonization at the intestinal and systemic phases.

Mohyla et al. (2007) observed that *Salmonella* load was significantly reduced in the upper digestive tract but not in the lower digestive tract when acidified sodium cholorite (produced by the combination of sodium chlorite with citric acid or sodium acid sulphate) was added to the drinking water at a level of 0.06% for the last 24 hours or 5 days. Similarly, Van Immerseel et al. (2006) reported that organic acids administered in feed and water was not effective further down the intestinal tract. According to some authors, most of the short-chain fatty acids (i.e. propionic, formic) used in diets or water are metabolized and absorbed in the upper gastro-intestinal segments of poultry (Thompson & Hinton 1997; Hamed et al. 2013). Thus, their role in modifying host microflora populations in the lower parts is limited (Józefiak et al. 2010). Recently, some researchers have suggested transport of short-chain fatty acids further down the gastrointestinal tract by microencapsulation in a lipid shell. The protective lipid matrix used for microencapsulation allows organic acids to have an effect all along the gastro-intestinal tract, since they are slowly released during digestion (Fernández-Rubio et al. 2009; Van Immersell et al. 2009). Gheisari et al. (2007) found that supplementation of 0.2% encapsulated organic acids to the diet might improve the proliferation of useful microflora (*Lactobacillus* spp.) and diminish the population of harmful bacteria (*Clostridium perfringens, Ecoli* and *Salmonella* spp.) in poultry gut contents.

It has been reported that medium-chain fatty acids (C6–C12; caproic, caprylic, capric and lauric acids) appear to be much more effective against *Salmonella* than short-chain fatty acids ($C \leq 4$; formic, acetic, propionic and butyric acids) (Van Immerseel et al. 2006). Moreover, Kwan and Ricke (2005) found that amongst the short-chain fatty acids, butyrate has the highest bactericidal against the acid-intolerant species such as *E. coli* and *Salmonella*. The mechanism of action of organic acids perhaps reflects their antibacterial nature, such as decreasing the pH of drinking water and reducing the buffering capacity of the feed with a subsequent effect on the physiology of the crop and proventriculus (Van Immerseel et al. 2006). The organic acids have the ability to change from un-dissociated to the dissociated form (depending on the environmental pH), which enhances their antimicrobial effect. When the acid is in the un-dissociated form it can freely diffuse through the semi-permeable membrane of the micro-organisms into the cell cytoplasm (Van Immerseel et al. 2006). Once in the cell, where the pH is maintained near 7, the acid will dissociate and suppress bacterial cell enzymes (e.g. decarboxylases and catalases) and nutrient transport systems (Huyghebaert et al. 2011).

The efficacy of an acid in inhibiting microbes is dependent on its pKa value, which is the pH at which 50% of the acid is dissociated. Efficacy of organic acids is generally improved with increasing chain length and degree of unsaturation (Huyghebaert et al. 2011). In general, variables that influence the antibacterial activity of organic acids are given as follows: (1) chemical formula, (2) pKa value of the acid, (3) chemical form (esterified or not, acid, salt, coated or not), (4) molecular weight, (5) the micro-organism-related minimum inhibitory concentration (MIC) value of the acid, (6) the nature of the micro-organism, (7) animal species and (8) the buffering capacity of the feed (Thompson & Hinton 1997; Patten & Waldroup 1988). Thus, it is obvious that each acid has its own spectrum of microbial activity related to a specific pH range, membrane structure and in-cell physiology of the microbiota species. Blends of acids represent an array of pKa values and are used because of the broader spectrum of activity.

3. Effect of organic acid on the gastrointestinal tract

Good intestinal health in the poultry industry is of great importance to achieve target growth rates and feed efficiency. Organic acid (1.0% sorbic acid and 0.2% citric acid) supplementation significantly increased the villus width, height and area of the duodenum, jejunum and ileum of broiler chicks at 14 days of age (Kum et al. 2010; Rodríguez-Lecompte et al. 2012). Garciá et al. (2007) reported that broilers fed diets containing formic acid had the longest villi (1273 and 1250 µm for 0.5 and 1.0% formic acid, respectively) compared with control (1088 µm). Similarly, crypts of jejunum were deeper in birds fed the formic acid diet (1.0%) than birds fed the antibiotic diets (266 vs. 186 µm, respectively; $P < .05$) in the same experiment. Thus, formic acid supplementation increased both the villus height and crypt depth. Short-chain fatty acids have been demonstrated to stimulate the proliferation of normal crypt cells, enhancing healthy tissue turnover and maintenance. This trophic effect was demonstrated by Frankel et al. (1994), who found an increase in villus height, crypt depth and surface area in the colon and jejunum of rats fed diets supplemented with butyric acid. Similarly, Leeson et al. (2005) and Panda et al. (2009) reported that butyrate, irrespective of concentrations (0.2%, 0.4% or 0.6%) in the broiler's diet, improved the villus length and crypt depth in the duodenum. Thus, butyrate supplementation could be highly helpful to young birds for intestinal development. In another study, the highest duodenal, jejuna and ileal villus heights were recorded in the birds fed diets supplemented with 3% butyric acid, 3% fumaric acid and 2% fumaric acid, respectively (Adil et al. 2010). The crypt depth in the duodenum, jejunum and ileum was not affected among different treatment groups. Moreover, the muscularis thickness was decreased in all the segments of small intestines (Adil et al. 2010). This reduction in the muscularis thickness is helpful in improving the digestion and absorption of nutrients as reported by Teirlynck et al. (2009) that the thickening of mucous layer on the intestinal mucosa contributes to the reduced digestive efficiency and nutrient absorption.

In some studies, organic acid salt also significantly improved villus height in the duodenum, jejunum and ileum. Pelicano et al. (2005) reported higher villus height in the ileum with the diet based on organic acid salts compared with diet fed without mannan oligosaccharide + Organic acid salt. Paul et al. (2007) found that the histology of intestinal parts revealed that organic acid salt (ammonium formate and calcium propionate) supplementation increased the villus height of different segments of the small intestine than the control group possibly by reducing intestinal colonization of pathogenic and non-pathogenic bacteria. The increase of villus height of different segments of the small intestine may be attributed to the role of the intestinal epithelium as a natural barrier against pathogenic bacteria and toxic substances that are present in the intestinal lumen. Pathogen substances cause disturbances in the normal micro-flora or in the intestinal epithelium that may alter the permeability of this natural barrier, facilitating the invasion of pathogens modifying the metabolism (ability to digest and absorb nutrients) leading to chronic inflammatory processes at the intestinal mucosa (Khan 2013). Consequently, there is a decrease in the villus height, increase in the cell turnover and decrease in the digestive and absorptive capacities (Pelicano et al. 2005). So organic acid salts reduced the growth of many pathogenic intestinal bacteria. Consequently, organic salts reduced intestinal colonization and infectious process, thereby, decreased inflammatory process at the intestinal mucosa, this improved villus height and function of secretion, digestion and absorption of nutrients (Iji & Tivey 1998).

4. Effect of organic acid on nutrient digestibility

Organic acids normally used as an acidifier in poultry feeds have been considered to be attractive alternatives for improving nutrient digestibility. Ghazala et al. (2011) reported that dietary 0.5% of either fumaric or formic acid and 0.75% of acetic or 2% citric acid improved both ME and nutrient digestibility, that is, crude protein (CP), ether extract (EE), crude fibre (CF) and nitrogen-free extract (NFE) of broiler diets. Moreover, Hernández et al. (2006) and Garciá et al. (2007) reported that supplementation of formic acid (0.5% or 1.0%) in broiler finisher diet was found to improve apparent ileal digestibility (AID) of dry matter (DM) (67.8% or 68.8%, respectively) and CP (72.5% or 73.5%, respectively) as compared with control (56.4% DM and 60.7% CP). Similarly, 2% citric acid in the broiler diet also increased the retention of DM, CP and neutral detergent fibre (Ao et al. 2009). In one study, the gross energy, CP and EE digestibility at 19 days was found to be 76.20%, 72.62% and 67.65% in the non-supplemented group, which was significantly lower as compared with 78.01%, 76.07% and 72.85% in the 2.0% supplemental ascorbic acid group, respectively. The results were similar at 39 days of lower nutrient digestibilities in the nonsupplemented group as compared with the ascorbic-acid-added diet (Lohakare et al. 2005).

The low ME of a soybean meal for poultry is due mainly to the very poor digestibility of the carbohydrate fraction. The galacto-oligosaccharides in the soyabean meal cannot be digested in the small intestine of poultry because of the absence of the endogenous α-(1, 6)-galactosidase enzyme (Lee et al. 2014). Ao (2005) added 2% citric acid to the soyabean meal as substrates in the *in vitro* trial. The result indicated that addition of citric acid increased the activity of α-galactosidase resulting in decreased the crop pH. He reported that citric acid decreased the crop pH and enhanced the activity of α-galactosidase in the crop *in vivo* trial. Organic acid supplementation improved CP and ME digestibilities by reducing microbial competition with the host for nutrients, endogenous nitrogen losses and production of ammonia (Omogbenigun et al. 2003).

Biggs and Parsons (2008) reported that apparent amino acid digestibility (AAD) was consistently lower at 21 days for chicks fed 4 and 6% gluconic acid in broiler diets. This response was probably at least partially due to an increase in the digesta passage rate that caused mild diarrhoea, which was visually observed in these chicks. Indeed, birds fed the 6% gluconic acid diet produced excreta that contained 4% more water than birds fed the control diet (80.7% vs. 76.8%, $P < .05$). When citric acid (3% or 4%) was supplemented to chicks, it improved AAD at 4 days (3% units), but this effect did not carry through to 21 days. The results for AAD indicated that gluconic acid and citric acid had no consistent effects. Samanta et al. (2010) reported that organic acids raised gastric proteolysis and improved the digestibility of protein and amino acids. Organic acids lowered the pH of the chyme and thus enhanced the digestibility of protein. It is thought that the lower pH of the digesta due to the organic acid supplementation might increase the pepsin activity (Afsharmanesh & Porreza 2005). Proteolysis of proteins by pepsin produced peptides which activate the release of hormones including gastrin and cholecystokinin. The pancreatic secretion increased by organic acids to enhance the production of pancreatic juice, which led to better digestion of proteins due to the high concentration of trypsinogen, chymotrypsinogen A, chymotrypsinogen B, procarboxy peptidase A and procarboxy peptidase B (Adil et al. 2010). According to Van Der Sluis (2002), the positive effect of organic acids on digestion was related to a slower passage of feed in the intestinal tract, a better absorption of the necessary nutrients and less wet droppings. Centeno et al. (2007) found that the AID of CP and dispensable and indispensable amino acids were not affected by the addition of citric acid and the microbial phytase enzyme in the broiler diet. They did not observe a synergistic effect of microbial phytase and dietary citric acid on amino acid digestibilities. A possible explanation may be that the citric acid complexed with calcium (Ca) and decreased its binding to phytate, increasing the susceptibility of the phytate to hydrolysis by the enzyme. However, Emami et al. (2013) reported that broilers fed the control diet (without microbial phytase enzyme and organic acid) had the lowest CP and EE digestibility (0.7751 and 0.7949, respectively), which were improved ($P < .001$ and $P = .010$, respectively) by the addition of Phytase + organic acid (0.8858 and 0.8561, respectively) to the control diet. Smulikowska et al. (2009) reported that fat-coated organic acid preparations increased nitrogen (N) retention in comparison with the un-supplemented control diet. The increase in N retention can be connected with greater epithelial cell proliferation in the gastrointestinal tract. Non-protected organic acids added into poultry feed are readily digested (Sugiharto 2014), while the fat-coated preparation prevented dissociation of organic acids in the stomach and helped to address their bioactivity towards distal parts of the intestine and effectively modulate the intestinal microflora and mucosal morphology in chickens (Hu & Guo 2007).

Dietary addition of organic acids can also improve the digestibility of minerals and increase the utilization of the phytate phosphorus (P) (Bioling et al. 2000; Park et al. 2009). Nourmohammadi et al. (2012) reported that addition of the microbial phytase enzyme and 3% citric acid to the broiler diet caused improvement in ileal nutrient (CP, AME, Ca and total P) digestibility and increased mineral retention of broiler chickens. Although the cooperation between organic acids and phytase is not clear, there are two possibilities for this; firstly, organic acids may increase total P absorption by increasing P solubility in digesta and as a result, prolonging the transferring time in small intestinal; secondly, organic acids may provide better conditions for the acting phytase by acidification of the diet and digestive fluids (Han et al. 1998). Supplementation of the mixture of organic acid (propionic acid and sodium bantonite) in the broiler diet caused an increase in digestibility and availability of nutrients (such as Ca and P) due to developing desirable microflora (*Lactobacillus* spp.) of the digestive tract, which in turn results in increasing mineral elements' retention and bone mineralization (Ziaie et al. 2011). The acidic anion has been shown to complex with Ca, P, magnesium and zinc, which results in an improved digestibility of these minerals (Edwards & Baker 1999).

5. Effect of organic acids on immunity

Several studies demonstrated that organic acids could stimulate the natural immune response in poultry. Lohakare et al. (2005) found that the infectious bursal disease (IBD) titres measured postvaccination showed significantly higher IBD titres in the ascorbic acid (0.2%) supplemental group. They explained that the possibility of increasing the antibody to vaccination in ascorbic-acid-supplemented chickens might be due to speeding up of differentiation of lymphoid organs by increasing the activity of the hexose monophosphate pathway, thus increasing the circulating antibody. In the same study, the CD4 and TCR-II cells were found significantly higher in the 0.1% ascorbic acid group as compared with control. The CD4 lymphocyte recognizes the antigen in the context of the major histocompatibility complex-class II histocompatability molecule. The TCR-II lymphocytes have T-cell antigen receptors composed of a heterodimer 2 polypeptide (α and β), which acts as an antigen-binding site. These cells participate in the immune response to the exogenous antigen, which presents to them by antigen-presenting cells. This stimulates the synthesis of Interleukin-2, which activates CD8, natural killer (NK) cells and B cells. The significant increase of CD4 and TCR-II lymphocytes by addition of organic acid indicated the increase of lymphocyte to exogenous antigen and provokes immune response quickly. Houshmand et al. (2012) found that at 21 days of age of the broiler, dietary addition of organic acids (Sunzen Corporation SdnBhd, Malaysia; 0.15% in a starter diet) resulted in significant increases in antibody titres against Newcastle disease. However, at 42 days of age, a non-significant difference ($P > .05$) was noticed between treatments. Similarly, antibody titres against Newcastle disease in laying hens also increased by increasing the levels of formic acid (0.5–1.5 mL/L; Abbas et al. 2013).

The immune system of birds is complex and is composed of several cells and soluble factors that must work together to produce a protective immune response. Major constituents of the avian immune system are the lymphoid organs. Abdel-Fattah et al. (2008) and Ghazala et al. (2011) reported that birds fed an organic-acid-supplemented diet had heavier immune organs (bursa of Fabricius and the thymus) and also a higher level of globulin in their serum. Concentration of globulin is used as an indicator for measuring immunity response. Above workers also suggested that the improvement in bird immunity could be related to the inhibitory effects of organic acids on gut system pathogens. Citric acid supplementation (0.5%) enhanced the density of the lymphocytes in the lymphoid organs, enhancing the non-specific immunity (Haque et al. 2010). Phenyllactic acid is an organic acid that is produced as a by-product of phenylalanine metabolism. Wang et al. (2009) found that the dietary supplementation of the phenyllactic acid increased in the short term the lymphocyte percentage in layers. The results showed that organic acid supplementation also caused hyperthyroidism and peripheral conversion of T4–T3 which meant that these birds had better immunocompetence and bursa growth (Abdel-Fattah et al. 2008).

Rodríguez-Lecompte et al. (2012) reported that supplementation of combined probiotics and organic acids (sorbic and citric acid) to broiler diets resulted in better responses of gut morphology and their effects were more apparent in the duodenum and ileum when the gut was fully developed. When considering the immune response, a combination of probiotics and organic acids was capable of altering TLR-2 and cytokine profiles. They were able to down-regulate caecal tonsil TLR-2, ileal IL-12p35 and IFN-γ at d 11 and up-regulate caecal tonsil IFN-γ and ileal IL-6 and IL-10 at d 22. The down-regulation of the cytokines implies that supplementation of combined probiotics and organic acids supported an anti-inflammatory effect via Th-2 associated pathways involving cytokines such as IL-10. Furthermore, TLR-2, IL-12p35 and IFN-γ responses in birds supplemented with combined probiotics and organic acids for 7 days followed the same trend as those supplemented for 14 days, indicating that shorter periods of supplementation might be enough to elicit beneficial responses (Rodríguez-Lecompte et al. 2012). Emami et al. (2013) found that supplementation of phytase and organic acids improved intestinal integrity and immune response of broilers fed diets low in available phosphorous. They reported that broilers fed Phytase + organic acid diet showed higher ($P < .001$) immunoglobulin G (IgG; 2.27) in the primary and also higher ($P < .001$) total immunoglobulin (7.84) and IgG (5.74) in the secondary response compared with control. In another study, Park et al. (2009) noticed that immunoglobulin-Y (IgY) levels significantly increased with the addition of organic acids (0.2% organic acid to the 0.3% available phosphorus; 3.88% Ca in a layer diet of hens aged 75 weeks with production of 73.3%), and it appeared that adding organic acids to the feed influenced the digestive mucous membrane and improved the immune function. In this study, a commercial organic acid named 'Lactacid' (Ca-formate 17%, Ca-propionate 5%, Ca-lactate 15%, citric acid 27% and carrier 36%), Eunjin Bio. Co., Cheonansi, Korea) was used. However, more studies may be needed to verify the effects of organic acids on the immune properties of poultry.

6. Effect of organic acid on broilers' performance

In poultry production, organic acids have not gained as much attention as in pig production (Langhout 2000). High levels of production and efficient feed conversion are the need of the modern broiler industry which to a certain extent could be achieved by the use of specific feed additives. Organic acids have growth-promoting properties and can be used as alternatives to antibiotics (Fascina et al. 2012). Dietary supplementation of organic acids increased the body weight and feed conversion ratio (FCR) in broiler chicken. Panda et al. (2009) reported that 0.4% butyrate in the broiler diet was similar to antibiotics in maintaining body weight gain (646 and 642 g, respectively) but superior for FCR. No added advantage on these parameters was obtained by enhancing the concentration of butyrate from 0.4% to 0.6% in the diet. Contrary to the findings of the above study, Leeson et al. (2005) and Antongiovanni et al. (2007) suggested a lower level (0.2%) of butyrate to maintain the performance of broiler chickens. Adil et al. (2010, 2011b) found that the highest weight gains were achieved in the birds fed 3% fumaric acid as compared to the group fed diet supplemented with 3% lactic acid. Chicks fed the diet supplemented with organic acids showed a significant ($P < .05$) improvement in the FCR as against the chicks fed the control diet. The improvement in the FCR could be possibly due to better utilization of nutrients resulting in increased body weight gain in the birds fed organic acids in the diet. The above workers also conducted another trial, in which broilers were given basal diet supplemented with 2–3% each of butyric acid, fumaric acid and lactic acid (Adil et al. 2011a). Cumulative feed consumption was found to be decreased in all the groups fed organic acids compared to the control group. The reduction in the feed intake might be due to the strong taste associated with the organic acids which would have decreased the palatability of the feed, thereby reducing feed intake. Chicks fed the diets supplemented with organic acids showed a significant improvement in the FCR as against the chicks fed the control diet. The improvement in FCR could be possibly due to lesser feed intake resulting in increased body weight gain because of better utilization of nutrients in the birds fed organic acids in the diet. Recently, Brzóska et al. (2013) reported that organic acid (0.3–0.9%) had a growth-enhancing and mortality-reducing effect in broiler chickens, with no significant influence on carcass yield or proportion of individual carcass parts.

The organic acid mixtures might be more efficient than some antibiotic growth promoter in improving broiler performance. In one study, two commercial mixtures of organic acids (Galliacid® and Biacid®) were supplemented in basal diets with 0.06% Galliacid, 0.1% Biacid or 0.02% Eneramycin® (Hassan et al. 2010). Galliacid® consisted of a mixture of fumaric acid, calcium format, calcium propionate, potassium sorbate and hydrogenated vegetable oil. These organic acids are coated and protected (microencapsulated) by a matrix of fatty acids. Biacid® consisted of a mixture of citric acid, calcium formate, calcium butyrate, calcium lactate, essential oils and flavouring compounds. The results showed that birds fed the Galliacid-supplemented diet had 16% more weight gain than the control; while those fed the Biacid- or Enramycin-supplemented diets recorded 3% and 5.5% more weight gain, respectively. Organic acids mixtures and Enramycin supplementation significantly improved FCR. Fascina et al. (2012) reported that the use of an organic acids mixture (comprising 30.0% lactic acid, 25.5% benzoic acid, 7% formic acid, 8% citric acid and 6.5% acetic acid) in broiler diets improved its performance as compared to the control diet at 42 days of age and organic acids provided better carcass characteristics. Recently, Hashemi et al. (2014) added an acidifier mixture (formic, phosphoric, lactic, tartaric, citric and malic acids) in the broiler diet at the rate of 0.15%. An increase in body weight gain was observed in the organic acid group (2402 g) compared to the control group (2276 g) at the end of 42 day of experiment. Such a positive impact of dietary acidifiers on growth performance might be attributed to a reduction of pH values in the feed and digestive tract, serving as a barrier against pathogenic organisms which are sensitive to low pH; the direct antimicrobial effect; the reduction in buffering capacity in conjunction with improving nutrient digestibility (Ghazala et al. 2011).

Improvements in broiler performance in response to organic acids are often reported. However, an important limitation is that organic acids are rapidly metabolized in the foregut (the crop to the gizzard), which will reduce their impact on growth performance (Lückstädt & Mellor 2011). Double salts of organic acids, such as potassium diformate and sodium diformate, which reach the small intestine, have been shown to have a significant impact on nutrient utilization (Lückstädt & Mellor 2011). Similarly, Paul et al. (2007) reported that ammonium formate or calcium propionate (0.3%) increased the live weight and live weight gain and FCR at day 21 in broiler chicken. Dibner and Buttin (2002) suggested that organic acids and their salts improve protein and energy digestibility by reducing microbial competition with the host for nutrients and endogenous nitrogen losses, by lowering the incidence of sub-clinical infections and secretion of immune mediators, by reducing the production of ammonia and other growth suppressing microbial metabolites. Probably these could be the reasons that organic acids or their salts improved feed utilization leading to better performance in the broilers.

Some studies also showed no performance difference, in comparison with the negative control and/or the birds fed antibiotics (Gunal et al. 2006; Abdel-Fattah et al. 2008; Vieira et al. 2008; Açıkgöz et al. 2011; Kopecký et al. 2012). There are conflicting results regarding the use of acidifiers in poultry and, according to Hernández et al. (2006), these effects depend on the chemical form of the acid, pKa values, bacterial species, animal species and the site of action of acids. Moreover, most of the studies that used organic acids as additives in broilers diets were conducted in low health challenge environments which could explain the inconsistent results, because the growth-enhancing effects of antimicrobial additives become apparent when chickens are subjected to suboptimal conditions, such as a less digestible diet or a less clean environment. This inconsistency would be related to the source, the amount of organic acids used and the composition of the diets.

Denli et al. (2003) reported that organic acid (mixture of propionic and formic acid) had no effect ($P > .05$) on the carcass yield, abdominal fat pad, abdominal fat percentage and liver weight at the end of the experiment compared with control.

Similar results were obtained by Skinner et al. (1991), who compared the effects of dietary fumaric acid supplementation at 0.125%, 0.25% and 0.50% on broiler performance from 0 to 49 days. Leeson et al. (2005) observed no effect on carcass weight when broilers were fed 0.2% or 0.4% butyric acid, whereas carcass weight and breast meat yield increased in birds fed 0.2% butyric acid when bacitracin methylene disalicylate or 0.1% or 0.2% butyric acid were compared in another trial. Similarly, Garcıá et al. (2007) reported that the carcass, right breast and right thigh yields of broilers at 49 days of age were unaffected by supplementation of formic acid (0.5% or 1.0%).

In the broiler industry, different organic acids have been used in the drinking water. Formic, acetic and propionic acids have very good solubility in water (Freitag 2007). The reduction of water pH from 7.4 to 4.5 with formic acid supplementation significantly decreased body weights at 21 and 42 days of age (Vieira et al. 2005; Açıkgöz et al. 2011). However, feed intake, FCR and mortality were not negatively affected by acidified drinking water. In contrast to the above studies, Pesti et al. (2004) indicated that acidified drinking water increased body weight in comparison to normal drinking water (2146 vs. 2117 g). In addition, Cornellison et al. (2005) found that water acidification did not affect the performance of turkeys and broilers. The discrepancies in these results are possibly consequences of differences in the type and concentration of organic acid used in the studies.

7. Effect of organic acid on layer performance

7.1. *Egg production*

Yesilbag and Çolpan (2006) reported that the average egg production (18 weeks of experiment) slightly increased in the experimental groups (91.03%, 90.94% and 91.30% for groups of 0.5%, 1.0% and 1.5% organic acid mixture, respectively) compared to the control group (85.76%), but the difference was not statistically significant. However, at the age between 24 and 28 weeks, the egg production of hens significantly increased more quickly in dietary organic-acid-supplemented groups as compared to the control group. In the same way, at the end of the experiment (when hens were between 36 and 38 weeks old), this parameter remained elevated in the supplemented groups and significantly decreased more slowly than in the control. The egg production was the highest in the experimental group receiving 1.5% organic acid supplementation. In two subsequent studies, average egg production per cent for the hens aged 70 weeks significantly increased by about 5.77% to 9.84% of laying hens fed on the basal diet supplemented by 0.078% of the organic acid mixture (formic acid and salt of butyric, propionic and lactic acids) when compared with the control diet (Soltan 2008; Rahman et al. 2008). In these experiments, feed conversion showed a significant ($P < .05$) improvement in laying hen groups which fed on the basal diet supplemented with organic acids at 0.026%, 0.052% and 0.078% by about 1.85%, 8.48% and 7.74%, respectively, when compared with the control. Wang et al. (2009) conducted the first experiment in which phenylalanine was applied as an acidifier in poultry diet. They reported that egg production in the phenyllactic acid treatments was improved by 1.55%, 2.64% and 2.69% at 0.5%, 1.0% or 1.5% organic acid, respectively, as compared with hens in the control group. The difference in egg production from d 0 to 35 was linearly increased as the phenyllactic acid levels increased ($P = .005$). They suggested that such an expected effect may have occurred because of the antimicrobial activity of the organic acid. If so, this may have improved the total nutrient digestibility, thereby improving the feed efficiency and the rate of egg laying. Youssef et al. (2013) reported that supplementation of encapsulated organic acid blend in layer diet improved the egg production (97.30%), feed intake (109 g/d) and feed conversion (1.81) of birds than the control group (88.5%, 15 g/d and 1.98, respectively). Similarly, Grashorn et al. (2013) reported that supplementation of an organic acids blend (contained 40% formic acid, 30% ammonium propionate, 26% lactic acid, 0.5% sorbic acid, 0.5% sodium benzoate and 3% carrier) to laying hens' diet resulted in increased ($P < .05$) average egg weight and egg production capacity during the experimental period by about 5% and FCR was improved ($P < .05$) by 3%.

In one study, supplementation of 0.2% organic acid to the 0.3% available phosphorus diet showed the best results in egg production, soft-shell plus broken egg production and FCR (Park et al. 2009). They concluded that addition of organic acid probably improved hen-housed egg production by decreasing soft-shell plus broken egg production, FCR and mortality, which were not statistically significant. A possible explanation for the low soft-shell plus broken egg production is that organic acid in Ca salt form may have provided some extra Ca, or organic acid may have improved mineral absorption for shell formation (Dhawale 2005). In contrast to the above study, citric acid did not improve egg production, egg mass, egg size, efficiency and the utilization of dietary phosphurus in laying hens fed a corn-soyabean meal diet containing 3.8% Ca (Boiling et al. 2000). The reason for the lack of effect in laying hens is unknown, but they hypothesized that it might be associated with the dietary Ca level. In that experiment, laying hen diet contained a much higher level of dietary Ca than chick diets (approximately 1%). It has been proposed that the ability of citric acid to improve phytate-P utilization is associated with its Ca-complexing property. The presence of excess Ca carbonate reduced the availability of phytin P in the intestinal tract of the layer.

Presently, drinking water acidification is preferred in the broiler and layer industry for improving performance (Chaveerach et al. 2004; Abbas et al. 2013) and different organic acids have been tested. Administration of acetic acid through drinking water at 0.06%, 0.04% and 0.02% groups significantly ($P < .01$) increased average egg production by about 20%, 15% and 10% compared with the control group during the hot season (Kadim et al. 2008). Recently, Abbas et al. (2013) reported that the laying hens that consumed drinking water with formic acid had greater egg production and improved feed conversion than the control during hot season. The results showed that egg production in the hens consuming water with 0%, 0.05%, 0.10% or 0.15% formic acid was approximately 72%, 80%, 86% and 88%, respectively. According to Mahdavi et al. (2005), the influence of organic acid on poultry production depends on gut flora and environmental temperatures. High ambient temperatures decrease serum and tissue vitamin and mineral concentrations in poultry (Khattak et al. 2012), which consequently causes a reduction in egg production as in the case of non-acidic treatment. Addition of organic acid to the drinking water helps to reduce the level of pathogens in the water and the crop/proventriculus, to regulate gut microflora, to increase the digestion of feed and to improve growth performance (Chaveerach et al. 2004). Furthermore, acidified water is expected to be more effective than dietary acidification, since organic acid intake is decreased depending on the reduction in feed consumption during heat stress (Abbas et al. 2013).

7.2. *Egg quality*

In previous studies, Gama et al. (2000) reported that with incorporation of organic acid into the layer diet for 4 or 8 weeks, the egg weight and egg quality were not affected. Another study showed that the dietary organic acid supplementation did not significantly affect egg-weight and egg-quality parameters (Yesilbag & Çolpan 2006). Recently, Youssef et al. (2013) also found that supplementation of organic acid did not significantly affect the egg-quality parameters excluding egg weight which was improved by 9.08%.

On the contrary, Kadim et al. (2008) reported that supplemental acetic acid produced a linear increase in external egg qualities such as egg weight, egg length, egg diameter and egg shell colour (L*, a*, b*). In one experiment, the best egg shell colour was obtained in the 0.2% organic acid and 0.4% available phosphorus layer diet. Supplementation of organic acid might improve the integrity of the reproductive organs, such as the shell gland in the oviduct, resulting in an improvement in egg shell colour (Park et al. 2009).

Yalcin et al. (2000) reported significant improvement in the albumen index ($P < .05$) and yolk index ($P < .05$) in layer hens supplemented with 1% lactic acid. The Haugh unit, which describes the height of thick albumen relative to the weight of the egg, is generally used as an indicator of storage quality. Few data are available regarding the effect of organic acid on the Haugh unit index. Yalcin et al. (2000), Kadim et al. (2008) and Wang et al. (2009) found that feeding hens diets containing lactic acid (1%), acetic acid (0.04–0.06%) and phenyllactic acid (0.2%) caused improvement in the Haugh unit score. Recently, Abbas et al. (2013) reported that feeding hens diets containing 0.01% or 0.15% formic acid can improve the Haugh unit score. In contrast to the above studies, Gama et al. (2000) reported that with the incorporation of organic acid into the layer diet for 4 or 8 weeks, a slight decline of haugh unit in hens receiving 0.05% organic acid supplementation was seen. The increased albumen per cent on organic acids supplementation and older age of hen might be responsible for the decreasing albumen index.

Kadim et al. (2008) also found that shell weight, shell thickness, albumen height and yolk pH were increased with increasing acetic acid concentrations in the drinking water. Park et al. (2002) also found that the egg shell strength increased with organic acid mixture treatment. Soltan (2008) reported that the improvement of egg thickness in laying hens' groups fed on the basal diets supplemented by 0.078% of organic acids by about 12.5% when compared with control. The egg shell strength was also improved at 8.73% and 7.08% when 0.2% phenyllactic acid was included (quadratic effect, $P < .05$) on d 21 and 35, respectively (Wang et al. 2009). Similarly, Abbas et al. (2013) found that egg shell thickness and egg grading from hens consuming acidified water containing formic acid were significantly greater than those from the control group. The above studies suggested that the improvement in egg shell quality might be a consequence of the increased mineral and protein absorption. The phenomenon of increased absorption is reflected in the increased calcium and protein deposits of the shell and contributes to improving the quality which may result in increased shell weight and thickness. The organic acid had a beneficial effect on calcium digestibility in layers. This may be because the addition of organic acids to the diet lowered diet acidity. Lowering the dietary pH may increase the solubility of minerals, thereby increasing the effectiveness of calcium. Some studies showed reduction in shell weight and thickness of layer eggs due to high ambient temperatures, which have been significantly improved following supplementation with organic acid (Soltan 2008; Abbas et al. 2013). It has been suggested that this response to organic acid may be influenced by factors such as dietary protein level, calcium level and the bird's metabolic rate (Kadim et al. 2008).

8. Conclusions

The results from the literature showed that organic acid supplementation, irrespective of type and level of acid used, had a beneficial effect on the performance of broiler and layer chicken. Some organic acids are more effective against acid-intolerant species such as *E. coli*, *Salmonella* and *Campylobacter*. Organic acids significantly increased the villus width, height and area of the duodenum, jejunum and ileum of broilers. Organic acids improved nutrient digestibility by reducing microbial competition with the host for nutrients and endogenous nitrogen losses, by lowering the incidence of subclinical infections and secretion of immune mediators, and by reducing production of ammonia and other growth-depressing microbial metabolites. Lack of consistency in demonstrating an organic acid benefit is related to uncontrolled variables such as buffering capacity of dietary ingredients, presence of other antimicrobial compounds, cleanliness of the production environment and heterogeneity of gut microbiota. Additional research can clarify the role and management of these factors.

Disclosure statement

No potential conflict of interest was reported by the authors.

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