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Different forms of butyric acid in poultry nutrition – a review

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ABSTRACT. Poultry production plays a significant role in meeting the ever-increasing global demand for animal protein. In recent years, poultry nutritionists have shown considerable interest in alternatives to antibiotic growth promoters, including organic acids. One of these alternatives is butyric acid, which exhibits antimicrobial activity, lowers the pH of intestinal contents, and reduces the abundance of pathogenic microorganisms. Various forms of butyric acid (such as salts, coated salts, and butyric acid glycerides) are utilised in poultry practice, each differing in effectiveness, bioavailability, stability and targeted release within the gastrointestinal tract. This article provides a comprehensive review of research on the effects of different forms of butyric acid on the functional status of the gastrointestinal tract, nutrient digestibility, slaughter value and production performance in poultry.

Introduction

Antibiotic growth promoters (AGPs) are defined as drugs that inhibit the growth of pathogenic bacteria, stabilise beneficial microflora, and are administered at subtherapeutic doses (Hughes and Heritage, 2004; Upadhayay and Vishwa, 2014). The use of these substances has increased with the intensification of livestock production owing to increased consumer demand and feed industry development (Ronquillo and Hernandez, 2017). The stimulatory effects of antibiotics on production were first observed in the early 1940s when chickens fed a compound feed containing tetracycline fermentation by-products showed higher growth rates compared to birds receiving feed without the additive. Since 1951, antibiotics have been extensively used in the feeding of various animal species (Castanon, 2007; Graham et al., 2007). Natural, synthetic, or semi-synthetic substances with antibacterial proper-ties have been employed not only as disease inhibitors, but also as feed additives to stimulate growth in livestock (Ronquillo and Hernandez, 2017).

Over the past decade, the role of AGPs has primarily focused on improving the production performance of animals across diverse environmental conditions. Their main function was to regulate the gastrointestinal microflora by inhibiting the growth of pathogenic microorganisms and their toxin production. The results included higher weight gains, better feed utilisation, reduced mortality, and increased resistance to coccidiosis in poultry. Additionally, improvements in nitrogen balance and diminished methane production have been observed (Grela and Semeniuk, 2006; Graham et al., 2007; Huyghebaert et al., 2011; Upadhayay and Vishwa, 2014).

Growing public health concerns and increased consumer awareness of the quality of animal products have led to greater scrutiny of AGPs applied

in animal nutrition. Raising resistance in strains of *Salmonella, Campylobacter, Enterococcus*, and *Escherichia coli* poses a significant threat to both human and animal health (Graham et al., 2007; Apata, 2009). Consequently, restrictions have been gradually imposed on the use of AGPs. For instance, in 1991, compounds like spiramycin, tylosin and bacitracin were withdrawn from use (Upadhayay and Vishwa, 2014). Furthermore, on January 1, 2006, the European Commission enacted a ban on the use of antibiotics as growth promoters in animal nutrition within the EU (Huyghebaert et al., 2011).

A consequence of the withdrawal of AGPs from animal nutrition was a deterioration in production performance due to increased feed consumption per kg of body weight gain, as well as a surge in gastrointestinal diseases, resulting in higher animal mortality rates. Consequently, it was necessary to increase the administration of therapeutic antibiotics (Casewell et al., 2003; Yegani and Korver, 2008; Brown et al., 2017). The solution has become the use of alternative substances to growth promoters to maintain animal health and performance (Huyghebaert et al., 2011). Feed additives such as probiotics, prebiotics, phytobiotic enzymes and acidifiers have gained particular importance in animal production systems. One of the primary advantages of these substances is their safety for both human and animal health, as they do not contribute to the development of antibiotic resistance.

Organic acids, particularly sodium butyrate, have emerged as noteworthy feed additives and are regarded as more effective alternatives to antibiotics. This efficacy stems from their antibacterial properties, ability to lower the pH of gastrointestinal contents, and overall health benefits to animals (Boling et al., 2000; Kim et al., 2005; Yadav et al., 2016). This review discusses published data regarding the use and benefits of different forms of sodium butyrate in poultry diets.

Characteristics of organic acids

Organic acids are prevalent compounds found in both plant and animal tissues. They are also produced during microbial fermentation of carbohydrates, mostly in the intestines of birds (Gadde et al., 2017). These acids typically exist in the form of salts, such as sodium, potassium, or calcium salts, and may be partially esterified. The advantages of salts over pure acids include their milder odour and water solubility, facilitating their incorporation into the feed production process

(Huyghebaert et al., 2011). Among the organic acids used in animal nutrition, two main categories are recognised, i.e., simple monocarboxylic acids (e.g., formic acid, acetic acid, propionic acid, and butyric acid) and carboxylic acids containing a hydroxyl group (e.g., lactic acid, malic acid, and citric acid) (Khan and Iqbal, 2016). Organic carboxylic acids are characterised by their R-COOH chemical structure (Hajati, 2018).

The aforementioned compounds have been used for decades as antibacterial and preservative agents in compound feeds and drinking water (Wang et al., 2009). In addition, they are recognized for their potential to enhance immunity, improve nutrient digestibility, and consequently they can be applied as alternatives to growth promoters in poultry nutrition (Van Immerseel et al., 2004; Nezhad et al., 2011; Jankowski et al., 2012). These acids vary in molecular weights and exhibit different water solubilities and dissociation constants (pKa). The ability of acids to lower the pH of the gastrointestinal tract and their antimicrobial activity depends on the pKa index, which represents the pH value at which half of the acid dissociates (Sugiharto, 2016). Most organic acids possessing antimicrobial properties have pKa values ranging from 3 to 5 (Khan and Iqbal, 2016). Acids can be employed individually, in mixtures, in liquid form or with solid carriers (Huyghebaert et al., 2011).

Factors influencing the antibacterial properties of organic acids include the pKa value, chemical form (esterified or not, acid, salt, encapsulated or not), molecular weight, types of microorganisms present in the feed or digestive tract, animal species, and buffering capacity of the feed (Khan and Iqbal, 2016).

Owing to their physicochemical properties, short-chain fatty acids (C1–C7), such as formic, acetic, propionic, and butyric acids, are mainly utilised in poultry nutrition (Dibner and Richards, 2005). These acids have higher pKa values, making them more effective as bacteriostatic compounds (Huyghebaert et al., 2011). Acidification of the feed and its content promote an increase in the abundance of beneficial bacteria (such as *Lactobacillus* and *Bifidobacteria*) and a reduction in undesirable microflora (*E. coli*), which compete with the host for available nutrients (Suresh et al., 2018). Decreasing the proliferation of potentially pathogenic and zoonotic bacteria, such as *E. coli* and *Salmonella* spp. in the feed and digestive tract, indirectly improves animal performance (Hernandez et al., 2006; Dehghani-Tafti and Jahanian, 2016).

Numerous studies have demonstrated the beneficial effects of lowering the pH of gastrointestinal contents on nutrient digestibility. Some acids increase proteolytic activity and the secretion of hormones such as cholecystokinin and gastrin (Khan and Iqbal, 2016), leading to improved protein digestibility and amino acid absorption (Qaisrani et al., 2015). The end products of protein digestion, pepsin, and the low pH of the digesta, stimulate the secretion of pancreatic enzymes. Additionally, some studies have shown an increase in the efficiency of feed enzymes, including phytase, following the use of acidifying additives in feed mixtures (Afsharmanesh and Pourreza, 2005; Vieira et al., 2018).

Organic acids have been shown to affect the intestinal mucosa and exert various immunomodulatory functions (Suresh et al., 2018). Supplementation of feed mixtures with organic acids have been demonstrated to increase the number of CD4 cells and T-cell receptors, which are responsible for a rapid immune response (Khan and Iqbal, 2016). Short-chain fatty acids (SCFAs) have been implicated in the regulation of genes involved in the growth, differentiation, proliferation, and apoptosis of epithelial cells (Hashemi and Davoodi, 2011).

Of particular interest in poultry production is short-chain butyric acid, which possesses strong antimicrobial properties, can serve as an energy source for colonocytes, enhances nutrient digestibility, and indirectly affects production performance (Gálfi and Neogrády, 2001; Leeson et al., 2005; Czerwiński et al., 2012; Elnesr et al., 2020).

Butyric acid characteristics

Butyric acid (BA) is a short-chain organic acid (C4) that was first identified in rancid butter in 1869 by Adolf Lieben and Antonio Rossi (Myers, 2007). Its molecular formula is $C_4H_8O_2$, with a structural formula of $CH_3CH_2CH_2COOH$ (Papatsiros et al., 2012; Kim et al., 2015). It has a molecular weight of 88.12 g/mol, a density of 0.958 g/ml and a pKa value of 4.82 (Ahsan et al., 2016). BA is a colourless, potentially volatile liquid with an unpleasant odour and taste. It is soluble in water and ethanol (Melaku et al., 2021). BA is naturally produced in the intestines of mammals and birds during anaerobic bacterial fermentation of dietary fibre (Kulcsár et al., 2017).

BA is used in the form of salts or as a protected form. Calcium or sodium salts of BA are preferred for their free-flowing nature, which facilitates the production of compound feed. Additionally, coated forms of butyric acid salts are often used due to their odourless properties (Kaczmarek et al., 2016). Scientific studies have demonstrated that the dissociation constant of sodium salt of butyric acid (SB) is 4.81, thus this acid undergoes degradation in the upper gastrointestinal tract (van der Wielen et al., 2000). The pH values range from 4.5 in the crop to 2.5 in the gizzard of birds (Denbow, 2015). As long as the ambient pH is lower than the pKa of BA, most of its molecules remain undissociated (Ahsan et al., 2016). Upon reaching the bird's stomach, Na+ ions are released from sodium salt and due to the low pH, the remaining fraction is quickly converted to a non-dissociated form referred to as butyrate (Elnesr et al., 2020). While this form of acid has antimicrobial activity, its rapid neutralisation in the duodenum limits the effectiveness of organic acid salts mainly to the upper gastrointestinal tract. In contrast, the non-dissociated form enables penetration into bacterial cells. Therefore, it seems reasonable to subject BA to processes that provide protection from dissociation, allowing for more effective antibacterial action in further sections of the bird's digestive tract, thereby reducing the number of pathogenic bacteria.

Various methods are employed to protect organic acids, with the most common being the encapsulation of BA salts with fats such as palm stearin or vegetable fats, along with salts derived from palm fatty acids, all of which have a high pKa (Deepa et al., 2018). When palm stearin is used as a coating, the resulting product contains only a small percentage of sodium butyrate (SB), requiring a higher feed intake to achieve sufficient levels of the active ingredient in the gastrointestinal tract. This approach ensures that BA is made available throughout the gastrointestinal tract rather than being limited to the initial sections (Mallo et al., 2012; Ahsan et al., 2016). Another method involves combining butyric acid with glycerol, which results in mono-, di- or triacylglycerol forms, making butyric acid stable and less susceptible to pH changes.Ultimately, these forms of the acid are released only in the presence of pancreatic lipase in the small intestine (Moquet et al., 2016).

The results of numerous studies have confirmed the superior effectiveness of protected forms of butyric acid compared to traditional forms in poultry nutrition (Smulikowska et al., 2009; Kaczmarek et al., 2016; Yin et al., 2016).

Effects of butyric acid on intestinal morphology and integrity

Environmental and nutritional factors play a significant role in shaping the intestinal morphology, integrity, and microbiota composition in birds. Pathogenic agents can induce detrimental effects such as leaky and inflamed intestines, dysbiosis and compromised intestinal barrier permeability in poultry (De Meyer et al., 2019; Diaz Carrasco et al., 2019). Intestinal dysfunction can result in reduced surface area of villi, impaired nutrient absorption and lower production performance (Melaku et al., 2021). Supplementation poultry rations with various forms of BA represents one approach to modulating the intestinal microflora composition and ensuring the maintenance of optimal intestinal health (Yadav et al., 2016).

The results of the studies have confirmed the beneficial effect of butyrate on small intestine morphology, such as stimulating the growth of intestinal villi (Guilloteau et al., 2010). The ratio of villus length to crypt depth is considered an important indicator of intestinal health (Kaczmarek et al., 2016). Both unprotected and enveloped forms of BA can improve duodenal and jejunal morphology. Incorporating BA into feed mixtures has been shown to increase the height of villi and the absorptive area of epithelial cells. For instance, broiler chickens receiving compound feeds with 0.5 or 1 g/kg sodium butyrate (SB) had significantly longer intestinal villi (by approx. 55 and 27%) on day 21 of rearing (Mallo et al., 2012). Other researchers have reported similar findings using 2 g/kg or more of sodium butyrate in broiler chicken rations over a 35-day period (Hu and Guo, 2007). The addition of encapsulated SB to poultry rations at levels of 1.05 or 0.3 g/kg has been shown to increase the height of jejunal intestinal villi (Czerwiński et al., 2012; Jerzsele et al., 2012). On the other hand, Smulikowska et al. (2009) found no effect on evaluated parameters in birds when administering 0.3 g/kg encapsulated SB to the feed mixture. Meanwhile, the application of BA glycerides (BAG) has been reported to exert contradictory effects on poultry intestinal morphology. For example, Leeson et al. (2005) observed no effect of BAG on intestinal villus height or crypt depth, while Antongiovanni et al. (2007) showed that birds fed a feed mixture with butyrate glycerides had significantly shorter villi in the ileum and jejunum, but at the same time increased depths of ileal crypts. These discrepancies in results could be attributed to the use of uncoated (CSB), whose

pKa value is lower than the pH of the small intestine, causing dissociation of the compound into ions that cannot be absorbed by enterocytes, and thus only interacts in the initial section of the intestine (van der Wielen et al., 2000). In contrast, protected forms can reach further segments of the gastrointestinal tract; however, the release of protected butyrate from the lipid coating requires the involvement of lipase (Moquet et al., 2016). In young chickens, this enzyme is not produced by the pancreas in sufficient quantity, resulting in limited butyrate release and no discernible effect on the height of villi during the early stages the birds' lives (Ahsan et al., 2016).

An increase in the area of intestinal villi may be correlated with an elevated rate of mucosal cell proliferation (Abdelqader and Al-Fataftah, 2016). The application of BA in various forms has been shown to improve the morphology of the small intestine of birds. These changes in epithelial structure may promote enhanced intestinal integrity and reduced penetration of antigens into the bloodstream (Elnesr et al., 2020). The addition of butyrate has been shown to stimulate the regeneration of intestinal epithelial cells and increase the thickness of intestinal mucosal (Hu and Guo, 2007). The improved intestinal condition could be attributed to increased blood flow and synthesis of gastrointestinal hormones. Butyrate was also demonstrated to increase the secretion of peptides that induce enterocyte proliferation, leading to more efficient repair of damaged mucosa and increased villus height (Elnesr et al., 2020).

Antibacterial properties of butyric acid

Campylobacter spp., *E. coli* spp., *Salmonella typhimurium, Shigella* spp., and other Gram-negative bacteria belong to common pathogens found in poultry (Adedokun and Olojede, 2019; Diaz Carrasco et al., 2019). The aforementioned microorganisms can damage the intestinal mucosa, leading to degradation of the structure of intestinal villi, reduced nutrient digestion and absorption, and consequently, a decline in the overall performance of bird rearing (Pan and Yu, 2014).

BA exhibits antibacterial properties that depend on its dissociation constant (pKa= 4.81) and pH of the gastrointestinal contents (Ahsan et al., 2016; Deepa et al., 2018). The non-dissociated form of BA facilitates its penetration into the interior of the bacterial cell. Once inside, dissociated butyrate ($CH_3CH_2CH_2COO-$) releases hydrogen

ions H^+ into the cytoplasm of pathogenic bacteria (Kim et al., 2005; Elnesr et al., 2020), which reduces the pH, leading to the inactivation of enzymes and disruption of DNA replication and bacterial metabolism (Waseem Mirza et al., 2016). The pathogen defends itself against the low pH by expelling hydrogen cations, which requires the release of energy and weakens the microorganisms (Deepa et al., 2018), ultimately leading to reduced growth and proliferation of pathogenic bacteria intolerant of an acidic environment with a pH around 3.5–4.0 (Melaku et al., 2021). The addition of 0.6% BA to compound feeds resulted in lower pH in the crop, proventriculus, gizzard and duodenum of broiler chickens (Panda et al., 2009); however, the pH of the ileal contents was shown to remain unchanged following the application of 0.3% BAG (Mahdavi and Torki, 2009) or 0.03% coated CSB (Czerwiński et al., 2012).

Supplementation of broiler chicken rations with SB has been shown to increase the abundance of beneficial *Bifidobacterium* and *Lactobacillus* bacterial strains in the small intestine (Abdelqader and Al-Fataftah, 2016). Other authors have observed a reduction in the counts of *E. coli* and an increase in the abundance of lactobacilli in the ileum of broilers fed a compound feed supplemented with SB on day 21 of the experiment (Makled et al., 2019). In birds, butyrate directly affects the production of mucin, which exhibits bactericidal activity against enteropathogens, including Gram-negative bacteria, such as *Salmonella* sp. and *E. coli*, as well as Gram-positive bacteria, such as *Clostridium* spp. (Van Immerseel et al., 2006). A reduction in the population of *Salmonella enteritidis* and *Typhimurium* bacterial populations in the faeces of broiler chickens receiving SB-supplemented feed mixtures has been confirmed by other authors (Van Immerseel et al., 2005; Fernández-Rubio et al., 2009). Butyrate may exert a beneficial effect by reducing the colonisation of the intestinal wall by harmful microorganisms, thereby decreasing the production of toxic compounds and minimising damage to intestinal epithelial cells (Antongiovanni et al., 2007; Elnesr et al., 2020). However, some studies have shown no significant effect of SB on reducing *E. coli* counts in the jejunum of broiler chickens (Hu and Guo, 2007; Chamba et al., 2014). In addition, the introduction of BA into poultry feed rations has been reported to selectively affect the beneficial microbiota, promoting homeostasis in the gastrointestinal microbial colony (Wu et al., 2018).

Immune and antioxidant properties of butyric acid

BA has been shown to stimulate the immune response by promoting the adhesion, proliferation and differentiation of immune cells (Abdelqader and Al-Fataftah, 2016; Deepa et al., 2018; Raza et al., 2019). Additionally, BA glycerides can affect the composition of intestinal microflora and serum metabolites, thereby contributing to the maintenance of intestinal homeostasis in birds (Yang et al., 2018).

Supplementation of feed mixtures with SB has been shown to increase thymus weight and antibody titres, and consequently improve humoral immunity of broiler chickens against Newcastle disease (NCD) infection (Sikandar et al., 2017; Lan et al., 2020). During the process of pathogenesis, interactions occur between bacteria and host cells. Butyrate has been found to downregulate the expression of bacterial invasion genes, thereby mitigating the virulence of pathogenic microorganisms (Van Immerseel et al., 2004). In addition, this acid stimulates the secretion of glycoprotein mucin, which enhances the protective barrier of the colonic mucosal epithelium (Leonel and Alvarez-Leite, 2012). The application of BAG at a dose of 0.4% in the feed mixture of broiler chickens has been found to increase the concentration of total protein, globulins and serum albumin in both control animals and birds exposed to *Eimeria maxima* protozoan infection (Ali et al., 2014). Zhang et al. (2011b) observed that enriching feed mixtures with 0.1% SB had no effect on the concentration of total protein in the serum of healthy birds; however, it increased this parameter in animals infected with *E. coli*. Conversely, other studies did not observe any significant changes in total protein concentration in the serum of birds fed mixtures containing 0.3% BAG (Mahdavi and Torki, 2009) or 3.0% BA (Kamal and Ragaa, 2014). Nonetheless, the latter study reported a notable increase in serum globulin concentration in birds.

BA exhibits immunomodulatory and protective properties on macrophages in birds infected with *Salmonella typhimurium*. The addition of butyric acid inhibited the expression of interleukins (IL)-1, IL-6 and interferon (IFN), which are responsible for increasing mucosal permeability and regulating inflammation induced by lipopolysaccharide (LPS – an endotoxin found in the wall of Gram-negative bacteria), thereby maintaining immune homeostasis in broiler chickens (Zhou et al., 2014).

This inhibition is attributed to the inhibitory effect of butyrate on nuclear transcription factor (NFκB), which is activated upon contact with stressors or antigens (Melaku et al., 2021). In addition, supressed NF-κB activation leads to decreased levels of reactive oxygen species (ROS) and stimulates the expression of genes involved in antioxidant synthesis (Hamer et al., 2009; Moeinian et al., 2013). This mechanism of action helps protect the body from ROS-induced DNA, lipid and protein under oxidative stress conditions (Canani et al., 2011). Supplementing rations with various forms of BA increases the activity of superoxide dismutase (SOD) in the serum of birds, while decreasing the concentration of malondialdehyde (MDA), indicating an increased ability to scavenge free radicals and mitigate tissue and cellular damage. Catalase (CAT), alongside SOD, is another antioxidant enzyme involved in defence mechanisms against oxidative stress (Deepa et al., 2018). Broiler chickens receiving a compound feed with SB at 1 g/kg were characterised by reduced levels of tumour necrosis factor (TNF-α), IL-6, MDA and increased activity of serum antioxidant indicators (SOD, CAT) on day 21 of rearing (Zhang et al., 2011a). Under stress conditions induced by corticosterone injection, broiler chickens fed compound feeds containing 0.04% CSB exhibited increased CAT activity and decreased MDA concentrations in the breast muscles (Zhang et al., 2011a).

Butyrate has been shown to suppress inflammation, reduce tumour lesions, and alleviate oxidative stress by enhancing the protective barrier of the intestinal mucosa (Hamer et al., 2008).

Impact on digestibility and production performance

The digestion and absorption of nutrients depend, among other factors, on the condition of intestinal villi (Awad et al., 2015). The height of the villi impacts the available surface area for nutrient absorption, thereby affecting overall functionality and subsequent production outcomes. BA, upon release, can directly stimulate the growth of intestinal villi, thus increasing surface area for absorption, leading to improved digestibility and, consequently, feed utilisation (Melaku et al., 2021).

The absorption rate of acids and their effects on gastrointestinal tract structure are closely related to their forms. Unprotected butyrate primarily affects the environment of the crop, proventriculus, and gizzard, while fat-coated butyrate is released in response to

lipase activity in the stomach and small intestine, and ultimately absorbed in the entire gastrointestinal tract (Moquet et al., 2018). Butyric acid has been demonstrated to lower the pH of gastric contents, increases the conversion of pepsinogen to pepsin, improves protein digestibility, and stimulates nutrient absorption (Youn et al., 2005). In a recent study by Makowski et al. (2022a), it was demonstrated that turkeys receiving feed rations supplemented with butyric acid glycerides exhibited enhanced protein digestibility and a reduced pH in the stomach contents. Moreover, Smulikowska et al. (2009) showed that the introduction of CSB at 0.3 g/kg into feed mixtures for broiler chickens significantly increased the apparent digestibility of total protein and organic matter, without affecting the digestibility of crude fat in broiler chickens. Similar results were obtained by Qaisrani (2014), who observed improved protein digestibility in the proventriculus of birds administered a protected form of butyrate. Other studies have reported enhanced apparent digestibility of crude fat and apparent metabolizable energy in broiler chickens fed compound feeds containing CSB (Kaczmarek et al., 2016). Additionally, birds receiving butyrate-enriched mixtures demonstrated an enhanced feed conversion ratio and higher weight gain. This acid can elevate cellular concentration of Ca^{2+} ions in pancreatic islets, thereby increasing amylase secretion (Katoh and Tsuda, 1987). Moreover, it is characterised by the ability to suppress the development of bile salt-degrading bacteria, which in turn reduces nutrient utilisation by microorganisms, consequently improving the digestibility and absorption rate in broilers (Melaku et al., 2021). The direct action of BA in the gastrointestinal tract exerts beneficial effects on production results, including weight gain, feed intake, and feed conversion ratio (Leeson et al., 2005; Antongiovanni et al., 2007; Panda et al., 2009; Chamba et al., 2014). Only protected sources of butyrate can effectively reach the small intestine of birds, contributing to their performance and improved utilisation of feed ingredients (Smith et al., 2012). The application of BAG or CSB in poultry rations at 2 or 4 g/kg has been shown to improve final body weight and reduce the feed conversion ratio of birds (Taherpour et al., 2009; Mansoub, 2011; Ali et al., 2014; Makowski et al., 2022b).

The available literature indicates that both unprotected BA in the form of salts, as well as its protected forms, can be used as alternative additives to growth promoters, improving weight gain and feed conversion ratio in poultry. However, there are many studies that have failed to demonstrate the effect of

BA, regardless of the form used, on improving poultry rearing performance (Mahdavi and Torki, 2009; Irani et al., 2011; Zhang et al., 2011a; Czerwiński et al., 2012; Cerisuelo et al., 2014).

Carcass quality and chemical composition of breast muscle

BA has a direct effect on the proliferation, maturation and differentiation of mucosal cells, as it can affect gene expression and protein synthesis, which consequently improves bird production and carcass quality (Sengupta et al., 2006). CSB demonstrates superior bioavailability in the small intestine of birds, leading to improved nutrient utilisation (Smith et al., 2012). Similarly, BA glycerides are less sensitive to low gastric pH and can reach further sections of the gastrointestinal tract, where the undissociated form of the acid is released by lipase (Ali et al., 2014). The released BA directly affects intestinal morphology and digestive processes, thereby improving feed utilisation and slaughter value. The stimulatory effect of BA on improving carcass quality indices has been documented in various studies (Bedford et al., 2017; Mátis et al., 2019). A study by Makowski et al. (2022b) showed that turkeys fed BAG-enriched compound feeds had improved slaughter value, while the addition of CSB increased the proportion of breast muscle in the birds' carcasses. It is worth noting that the weight of breast muscle and dressing percentage improved by butyric acid addition are positively correlated with the final body weight of the animals. Similar results were also observed in birds that received feed rations supplemented with unprotected butyric acid (Leeson et al., 2005; Panda et al., 2009).

Furthermore, in the same study, Makowski et al. (2022b) found that turkeys fed compound feeds supplemented with BAG had lower crude fat content in their breast muscles. Bedford et al. (2017) reported an increase in breast muscle weight and a decrease in intra-abdominal fat in broiler chickens receiving rations supplemented with BAG. Similar results were obtained by Yin et al. (2016), who found that the content of intramuscular and abdominal fat was lower in broiler chickens fed compound feeds supplemented with BAG. The latter authors hypothesised that BA could inhibit lipolysis and lipogenesis pathways, thereby potentially reducing fat deposition in the carcasses or breast muscles of birds (Heimann et al., 2015; Yin et al., 2016).

Conclusions

In summary, various forms of butyric acid (BA) can serve as an alternative to antibiotic growth promoters in poultry nutrition. BA has demonstrated its ability to maintain a healthy gastrointestinal tract and it plays a crucial role in preserving the integrity of the intestinal mucosa. Butyrate selectively stimulates the development of the beneficial microbiota and helps maintain microbial balance in the gastrointestinal community due to its antibacterial properties. The aforementioned research results confirm that the inclusion of BA in poultry feed enhances the health, digestibility, and growth performance of birds. BA is an increasingly utilised feed additive in poultry nutrition, and the available literature supports its effectiveness across all its forms.

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Conflict of interest

The Authors declare that there is no conflict of interest.

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